DTIC FILE COPY

AD-E 5?? ?41 Copy 32 of 100 copies

2

IDA PAPER P-2251

WEAPON RELIABILITY AND LOGISTIC SUPPORT COSTS IN A COMBAT ENVIRONMENT

AD-A223 314

Karen W. Tyson
Stanley A. Horowitz
Peter Evanovich
D. Graham McBryde
Mitchell A. Robinson
Barbara Junghans
Mei Ling Eng

August 1989

Prepared for
Office of the Assistant Secretary of Defense
(Production and Logistics)

INSTITUTE FOR DEFENSE ANALYSES
1801 N. Beauregard Street, Alexandria, Virginia 22311-1772

IDA Log No. HQ 89-34579

DEFINITIONS

IDA publishes the following documents to report the results of its work.

Reports

Reports are the most authoritative and most carefully considered products IDA publishes. They normally embody results of major projects which (a) have a direct bearing on decisions affecting major programs, or (b) address issues of significant concern to the Executive Branch, the Congress and/or the public, or (c) address issues that have significant economic implications. IDA Reports are reviewed by outside panels of experts to ensure their high quality and relevance to the problems studied, and they are released by the President of IDA.

Group Reports

Group Reports record the findings and results of IDA established working groups and panels composed of senior individuals addressing major issues which otherwise would be the subject of an IDA Report. IDA Group Reports are reviewed by the senior individuals responsible for the project and others as selected by IDA to ensure their high quality and relevance to the problems studied, and are released by the President of IDA.

Papers

Papers, also authoritative and carefully considered products of IDA, address studies that are narrower in scope than those covered in Reports. IDA Papers are reviewed to ensure that they meet the high standards expected of refereed papers in professional journals or formal Agency reports.

Documents

IDA Documents are used for the convenience of the sponsors or the analysts (a) to record substantive work done in quick reaction studies, (b) to record the proceedings of conferences and meetings, (c) to make available preliminary and tentative results of analyses, (d) to record data developed in the course of an investigation, or (e) to forward information that is essentially unanalyzed and unevaluated. The review of IDA Documents is suited to their content and intended use.

The work reported in this document was conducted under contract MDA 903 84 C 0031 for the Department of Defense. The publication of this IDA Paper does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of that Agency.

This Paper has been reviewed by IDA to assure that it meets the high standards of thoroughness, objectivity, and appropriate analytical methodology and that the results, conclusions and recommendations are properly supported by the material presented.

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY ***(Leave blank)***

2. REPORT DATE
August 1989

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Weapon Reliability and Logistic Support Costs in a Combat Environment

5. FUNDING NUMBERS
C-MDA 903 84 C 0031

TA-T-B6-425

6. AUTHOR(S)
Karen Tyson, Stanley Horowitz, Peter Evanovich, D. Graham McBryde, Mitchell Robinson, Barbara Junghans, Mei Ling Eng

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Institute for Defense Analyses
1801 N. Beauregard Street
Alexandria, VA 22311

8. PERFORMING ORGANIZATION REPORT NUMBER
IDA Paper P-2251

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Assistant Secretary of Defense (Production and Logistics)
The Pentagon
Washington, DC 20301

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

This paper reports on the development of a methodology for assessing the tradeoffs between equipment reliability and logistic support under combat conditions. In theory, improvements in reliability have two payoffs--cost is lower and sortie generation capability is higher. This analysis estimates the magnitudes of these payoffs, using the F-15 as an example, under baseline conditions and under conditions of maintenance delay, battle damage, and attrition. In the most severe combat condition case, higher reliability results in a one-third increase in the number of sorties achieved, at one-third the spares cost per sortie. Challenging sortie schedules were also examined. In the most severe case--a 30-day surge situation with maintenance delay, attrition, and the battle damage--the high-reliability fighter achieved 358 sorties, vs. only 233 for the normal-reliability case. The paper also discusses possible methods for doing the same type of analysis for new systems, before data on costs and demands for parts are available.

14. SUBJECT TERMS
Cost, Reliability, Logistics, F-15

15. NUMBER OF PAGES
160

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

IDA PAPER P-2251

WEAPON RELIABILITY AND LOGISTIC SUPPORT COSTS IN A COMBAT ENVIRONMENT

Karen W. Tyson
Stanley A. Horowitz
Peter Evanovich
D. Graham McBryde
Mitchell A. Robinson
Barbara Junghans
Mei Ling Eng

August 1989

IDA

INSTITUTE FOR DEFENSE ANALYSES

Contract MDA 903 84 C 0031
Task T-B6-425

PREFACE

This paper was prepared by the Institute for Defense Analyses (IDA) for the Office of the Assistant Secretary of Defense (Production and Logistics), under Contract No. MDA 903 84 C0031, Task T-B6-425, Weapon Reliability and Logistic Support Costs in a Combat Evnironment.

The purpose of the study is to develop and test a methodology for assessing the cost and performance trade-offs between equipment reliability and logistics support under combat conditions, to determine whether reliability affects sortie generation capability and costs and, if so, to what extent.

This paper was reviewed within IDA by Dr. Jeffrey Grotte, Dr. Peter Brooks, and Mr. Paul F. Goree.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to the individuals and organizations who contributed to this study. We would like to thank Col. Larry D. Griffin who served as cognizant official for the study. We would also to thank Mr. Thomas Parry, Mr. Martin Meth, Lt. Col. Larry Jordan and Mr. Russ Shorey.

The organizations that contributed information to the study include:

- U.S. Air Force, especially Air Force Logistics Command, Rome Air Development Center, and Air Force Systems Command (special thanks to Ms. Barbara Weiland of AFLC/LMSC/LOC)
- U.S. Army
- The Joint Integrated Avionics Working Group (JIAWG)
- McDonnell-Douglas Corporation
- Northrop Corporation
- Lockheed Corporation

Mr. Joseph Presta and Ms. Dianne St. Jean provided research assistance to the study.

TABLE OF CONTENTS

LIST OF FIGURES

Figure

LIST OF TABLES

EXECUTIVE SUMMARY

A. OBJECTIVE

This report discusses the development of a methodology for assessing the trade-offs between equipment reliability and logistic support under combat conditions to determine whether reliability influences sortie generation capability and costs and if so, to what extent.

Theoretically, improvements in the reliability of equipment have two important benefits:

- Program costs are lower. A given peacetime or wartime flying program could be completed at a lower cost for spare parts, manpower, support equipment, etc.
- The ability to generate sorties is greater. For a given set of support conditions, more missions can be flown. This would be particularly true in the case of sub-standard logistic support.

Support cost analysis should be used to examine the cost of alternative ways of achieving specified levels of combat effectiveness. Thus, there is a need for tools to evaluate the value of improved reliability in a wartime context. As with other aspects of system design, the desired level of reliability should be determined through explicit consideration of the environment in which the system is meant to be used.

It would be particularly beneficial if these methods of assessing the value of reliability could be applied to systems at stages of design or development when reliability can still be changed. Our goal is to develop a method for evaluating these issues that can also be used for prospective systems, such as the Air Force's Advanced Tactical Fighter (ATF).

B. APPROACH

The following three-step procedure was undertaken to fulfill this objective:

- Develop or adapt a model that can relate the reliability and cost of the components of a weapon system to the sortie generation capability of the system in a combat environment and to the cost of achieving that level of sorties. The Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC) model, a system used by the Air Force for sparing assessments, was selected to provide the basis for the Institute for Defense Analyses (IDA) system. The reasons for selecting this method are discussed in Section II.A.

- Demonstrate the methodology with an existing system. The F-15 was chosen for this purpose. (This procedure is detailed in the following paragraphs.)
- Develop techniques to allow analysis of the value of alternative levels of reliability for weapon systems that are in an early stage of the acquisition process. In future work, we will apply these techniques to a prospective system. (This analysis is also described in greater detail in the following paragraphs.)

1. The F-15 Analysis

In order to prepare to demonstrate the model on the F-15, we collected reliability and cost information on 387 modules (line replaceable units, or LRUs) and the parameters of a wartime flying scenario. We developed techniques to extend the combat environment that Dyna-METRIC can model.

We then used Dyna-METRIC to generate baseline war reserve spares kits (WRSKs) for a deployed F-15C squadron. Kits were developed for three levels of reliability--the normal level (based on actual failure rate data), a level reflecting failure rates 50 percent less than the normal level (a doubling of reliability), and a level reflecting failure rates 50 percent greater than the normal level. The effect of reliability on the cost of WRSKs was calculated. (These costs are considered to be reasonable approximations of actual WRSK costs, since this same methodology is used by the Air Force to develop spares packages.)

For all three levels of reliability, baseline spares packages were developed that allowed a squadron to meet the sortie goal for 30 days of simulated operations under standard assumptions about logistic support (resupply times and maintenance capability). Following Air Force practice, in the baseline case, simple repairs of failed components were allowed to begin on the 5th day of operations, while more complex repairs were delayed to the 30th day (and thus did not enter our calculations). No delays were associated with the performance of hands-on maintenance. No battle damage or attrition was assumed. The Air Force assumes no resupply for the first 30 days of a conflict, and we maintained this assumption.

A key aspect of our analysis involved modifying the baseline assumptions in ways that incorporated more of the characteristics of combat and developing sortie generation curves that reflected the new assumptions. In one excursion, a two-hour maintenance delay was associated with every repair action. In another, the onset of simple repairs of failed components was delayed for a longer period than in the baseline. In other excursions, attrition was incorporated, and a level of battle damage reflecting Vietnam experience was introduced into the analysis. These departures from the baseline were examined individually and together for all three levels of reliability.

The sortie profiles developed under the more combat-like assumptions were compared with those developed under the baseline. Inferences about whether reliability is likely to be more important in a combat environment than in a more benign environment could then be drawn.

This study did not examine all of the aspects of combat that might affect the value of reliability for producing additional sorties. For example, the loss of maintenance personnel (which enhances the value of reliability) and damage to runways (which may reduce the value of reliability) have not been considered. We believe that our approach to measuring the value of reliability achieves a reasonable compromise between completeness and ease of use, as discussed in Section II-A.

2. Analyzing Reliability Early in the Acquisition Process

Learning more about the value of improved reliability for existing weapon systems would be useful; this knowledge could help guide reliability improvement programs. Determining the value of reliability for systems in early stages of the design process would be more beneficial, because that is when improvements can be made most inexpensively and with the least disruption. The analytic procedure outlined in the preceding section must be modified to permit analysis of systems that do not yet have firm designs and detailed data on the costs and failure rates of their components are not yet available.

As a first step, we analyzed the F-15 as if it were a system in an early stage of development. We proceeded as if we had only the kind of aggregate information on the reliability of the F-15 and the cost of its components that is typically available at such a stage. In addition to assuming the average failure rate and cost of the components of the system, we assumed the availability of specific information on a small number of critical parts. We developed a set of disaggregation rules that (when applied to the aggregated F-15 data) yielded a fairly good approximation of the results achieved from using actual disaggregated data for the F-15. Simulating disaggregate data with aggregate data involved making assumptions about the joint distribution of the costs and the failure rates of components.

This approach is appropriate for analyzing the value of reliability in traditionally designed systems in which all of the components are attached in series and the failure of any component will cause the system to be unable to perform important aspects of its mission. The F-15 is such a system; the Advanced Tactical Fighter (ATF) is not.

In terms of reliability analysis, the avionics of the planned ATF differ from those of the F-15 in a number of important ways. The ATF avionics are being designed to achieve reliability and maintainability; the overall goal for the aircraft is to double the system reliability of the F-15. If this goal is achieved, planners hope that the need for the avionics intermediate shop can be eliminated, and support costs substantially reduced. Because the ATF is still in the initial design stages and because a two-level maintenance concept is being proposed for its avionics, the aircraft has been used as a case example to test the methodology developed in this study.

In the new avionics architectures, redundancy is expected to extend beyond the usual flight control systems to include other systems, and some components may be reconfigurable. (Redundancy means that a plane can have a failed component and still fly a sortie in full-mission-capable status. Reconfigurability means that a single component can perform the functions of a number of other components--it performs the function that is needed.) Dyna-METRIC is capable of handling cases of redundancy but has not been adapted to handle reconfigurability.

Other features that will increase the availability of ATF include enhanced fault detection, improved fault isolation, and fewer connectors, which have traditionally posed problems. While historically, the demand rates for parts in aircraft include false pulls (occasions when a failure is reported but nothing is found to be wrong), the rate of such errors should be reduced in the ATF. Another design improvement in the ATF is in the area of fault isolation. In contemporary aircraft, a failed line replaceable unit (LRU) may contain both functioning and failed shop replacable units (SRUs). In the ATF, isolating a fault to a single failed component at the flightline will often be possible, thus saving the cost of sparing for functioning components. Another feature planned for the ATF is to use the system's built-in test features to direct aircraft to different bases at the end of sorties, depending on the type of maintenance needed.

This paper contains alternative methods of analyzing the value of reliability in such systems by altering the demand rates for the new system. More complex modeling methods are also sketched.

C. CONCLUSIONS

Our objectives in this analysis were to assess the value of reliability in a wartime context and to begin to develop a method for assessing the reliability of prospective systems.

This analysis has shown that increasing system reliability results in increased sortie generation capability in wartime conditions. When maintenance delay is included in the analysis, higher reliability results in a 14 percent higher sortie rate, with a 62 percent reduction in spares cost per sortie. Another issue we wanted to explore is how stressful combat conditions affected the value of reliability. The usual planning factors often do not allow for some conditions that are very likely to occur. For example, battle damage places demands on the maintenance system and creates delays and downtime. It was unclear whether reliability might be unimportant when time must be taken to repair battle damage; our analysis indicated that, even with a relatively high level of battle damage, reliability has substantial value. In the most severe combat condition case --one that includes maintenance delay, attrition, and battle damage higher reliability results in a 33 percent increase in the number of sorties achieved, with a 67 percent reduction in cost per sortie.

Challenging sortie schedules also underscore the value of reliability. When spares are purchased for a normal sortie schedule and then a more challenging flight schedule is attempted, which may occur if a conflict becomes intense, reliability results in substantially more sorties. In the most severe case we examined--a 30-day surge situation with maintenance delay, attrition, and battle damage--the high-reliability fighter achieved 358 sorties, and the normal-reliability fighter achieved only 233.

The second major objective was to begin to develop a method for assessing the value of reliability in prospective systems. Our goal was to determine how this assessment can be made without a firm configuration or hard data on costs and failure rates. The IDA method allows for an initial assessment using with only the most general information. As the information expands and improves, the method accommodates it.

New system architectures present challenges for modeling. When reliability improvements can be made without major architecture change, the value of reliability can be assessed relatively easily. However, the advanced modular avionics architecture achieves greater system reliability through innovative designs in addition to increased inherent reliability of individual components. Improved fault detection and fault isolation, redundancy, reallocation of function, and reduced numbers of connectors are planned for the avionics systems, to be used on the ATF, the A-12, and the LHX, among others. Our conclusion is that the IDA models and methods can be adapted to assess the reliability of the most important features of these advanced architectures.

We have developed a framework for the analysis of reliability in new systems. This analysis can indicate the benefits of additional reliability, but it does not reflect all the costs or all the cost savings of additional reliability. Examining the cost dimension in more detail is essential, because cost must be balanced against the corresponding benefits.

D. RECOMMENDATIONS

Combat conditions--maintenance delay, battle damage, and attrition--substantially affect a squadron's ability to fly sorties. We believe that the Services should more closely consider combat conditions when determining which parts are mission essential and in building spares kits. The goal should be at least to spare as you would expect to fight. Perhaps it should be to spare as you fear you may have to fight.

The Services should consider instituting more reliability improvement programs for tactical aircraft. Spares cost savings aside, reliability has substantial payoff in combat.

The new avionics architectures must be evaluated using appropriate techniques. While these new architectures offer potential for significant support cost savings, they also present considerable difficulties in analysis, due to some special features not previously used or used less extensively. However, if these new architectures are not sufficiently analyzed, their potential benefits may not be adequately recognized during the acquisition process.

Additional research to refine and validate the method of assessing new systems should be performed. Analyses of additional systems are needed to examine whether different distributions should be used to develop simulated data for different kinds of systems.

In addition, the cost and cost savings from enhancing quality are vital questions that require further study. All phases of the acquisition process should be addressed. Cost estimating relationships that include reliability as well as physical and performance characteristics should be developed.

I. INTRODUCTION

A. OBJECTIVE AND APPROACH

This paper reports on the development of a methodology for assessing the trade-offs between equipment reliability and logistic support under combat conditions, to determine whether reliability influences sortie generation capability and costs, and if so, to what extent?

Theoretically, improvements in the reliability of equipment have two important benefits:

- Program costs are lower. A given peacetime or wartime flying program could be completed at a lower cost for spare parts, manpower, support equipment, etc.
- The capacity to generate sorties is greater. For a given set of support conditions, more missions can be flown. This would be particularly true in the case of sub-standard logistic support.

Support cost analysis should be used to examine the cost of alternative ways of achieving specified levels of combat effectiveness. Thus, there is a need for tools to evaluate the value of improved reliability in a wartime context. As with other aspects of system design, the desired level of reliability should be determined through explicit consideration of the environment in which the system is meant to be used. This implies not only using methods designed to reflect the combat environment as closely as possible but also applying the methods to data that reflect as combat-like a setting as possible.

It would be particularly beneficial if these methods of assessing the value of reliability could be used to assess the reliability of systems at stages of design or development when reliability can still be changed. Our goal is to develop a method for evaluating these issues that can also be used for prospective systems.

The following three-step procedure was undertaken to fulfill this objective:

- Develop or adapt a model that can relate the reliability and cost of the components of a weapon system to the performance of the system in a combat environment and to the cost of achieving that level of performance.
- Demonstrate the methodology with an existing system. The F-15 was chosen for this purpose.
- Develop techniques to allow analysis of the value of alternative levels of reliability for weapon systems that are in an early stage of the acquisition process. In future work, we will apply these techniques to a prospective system.

B. ISSUES

1. Model Selection

Since many models have been developed that can link reliability to the sortie generation capability of a squadron of aircraft, developing a model was not necessary. Two kinds of models were considered, Monte Carlo models (such as the Logistics Composite Module (LCOM), the Simulation Package for the Evaluation by Computer Technique of Readiness, Utilization, and Maintenance model (SPECTRUM) and the Comprehensive Aircraft Support Effectiveness Evaluation Model (CASEE)), and analytic models (such as the Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC), Availability Centered Inventory Model (ACIM) and Multi-Item, Multi-Echelon model (MIME)).[1]

We chose among these on the basis of ease of use and their ability to adequately capture the following four critical aspects of wartime operations:

- Ability to accommodate a varying sortie rate over the period of the conflict
- Ability to simulate an austere operating environment, one in which only limited repairs can be accomplished for at least part of the period being studied.
- Ability to simulate vulnerable logistic support, when delivery of additional spare parts is interrupted
- Ability to capture the effects of battle damage.

---

1 LCOM and Dyna-METRIC were developed by Rand, SPECTRUM by the Naval Air Development Center, CASEE by Information Spectrum Incorporated, ACIM by CACI and MIME by the Center for Naval Analyses.

The first three characteristics are important to examine because analysis that includes them is likely to demonstrate the value of reliability. If particularly challenging sortie rates are to be accomplished at critical junctures in the war, and if repairs are inhibited by the lack of equipment or spare parts, reductions in the number of aircraft that become inoperative due to parts failures could significantly affect mission accomplishment. If, however, most inoperative aircraft are not mission capable because they have been damaged by enemy fire, improved reliability is unlikely to affect mission accomplishment substantially.

Battle damaged aircraft are likely to remain inoperable, regardless of the reliability factor. To adequately analyze the net value of improved reliability in a battlefield context, all of these considerations must be examined.

Other aspects of combat operations not considered in our analysis of sortie generation capability include the availability of personnel to perform repair work and the effect of airfield damage. Estimates of the cost of personnel under different reliability assumptions will ultimately be included in our analysis, but spare parts and repair capability are the only resources that have been considered in determining the availability of aircraft. These factors seem most closely related to the reliability of equipment.

Dyna-METRIC was selected as our analytic tool; its structure is discussed in greater detail in Section II.

2. Demonstrating the Methodology with an Existing System

Our purpose was to show that a methodology based on the use of Dyna-METRIC could be used to assess the value of higher reliability under wartime conditions. To do this, we carried out the following sequence of steps:

- Data reflecting the reliability and cost of the components of the F-15 were gathered and the capability to use Dyna-METRIC to analyze these data was developed. While the reliability information was based on historical failure rates (refered to as historical data), it has been modified to better reflect failure rate behavior that might be observed in wartime. The modifications are mainly increases over and above peacetime failure rates for equipment that is used more intensely in wartime then in peacetime.
- A wartime flying scenario was obtained.
- Dyna-METRIC was used to generate war reserve spares kits (WRSKs) for a deployed F-15 squadron. Kits were developed for three levels of reliability:

the historical level, a level reflecting failure rates 50 percent less than the historical level (a doubling of reliability), and a level reflecting failure rates 50 percent greater than the historical level. In developing the WRSK kits, Dyna-METRIC was focused on buying parts that achieve specified levels of aircraft availability under a specified scenario as inexpensively as possible.

- The effect of reliability on the cost of WRSK kits was calculated. These costs are considered accurate, since this same methodology is used by the Air Force to develop spares packages.
- For all three levels of reliability, baseline sortie generation profiles were developed for 30 days of simulated operations under standard assumptions about logistic support (resupply times and maintenance capability). These profiles were compared with the levels of sortie generation called for by the scenario. Following Air Force practice, in the baseline case, simple repairs of failed components were allowed to begin on the 5th day of operations, more complex repairs were delayed to the 30th day (and thus did not enter our calculations). No delays were associated with the performance of hands-on maintenance, and no battle damage or attrition was assumed. All of our analyses (both the baseline and excursions from it) permitted cannibalization. The Air Force assumes no resupply for the first 30 days of a conflict, and we maintained this assumption.
- A key aspect of our analysis involved modifying the baseline assumptions in ways that incorporated more of the characteristics of combat and developing sortie generation curves that reflected the new assumptions. A two-hour maintenance delay was associated with every repair action. The onset of simple repairs (remove and replace) of failed components was delayed for a period longer than in the baseline. An attrition rate was incorporated, and a level of battle damage reflecting Vietnam experience was introduced into the analysis. These departures from the baseline were examined individually and collectively for all three levels of reliability.
- The sortie profiles developed under the more combat-like assumptions were compared with those developed under the baseline. Inferences about whether reliability is likely to be more important in a combat environment than in a more benign environment could then be drawn.

This study did not examine all the aspects of combat that might affect the value of reliability for producing additional sorties. For example, the loss of maintenance personnel (which enhances the value of reliability) and damage to runways (which may reduce the value of reliability) were not considered. We believe that our approach to measuring the value of reliability achieves a reasonable compromise between completeness and ease of use.

3. Analyzing Reliability Early in the Acquisition Process

Learning more about the value of improved reliability for existing weapon systems could help guide reliability improvement programs. Determining the value of reliability for systems in early stages of the design process, when improvements can be made most inexpensively and with the least disruption, would be very beneficial. Thus, the analytic procedure outlined in the preceding paragraphs must be modified to permit analysis of systems that do not yet have firm designs and detailed data on the cost and failure rates of their components are not yet available.

To develop and test such modifications, we analyzed the F-15 as if it were in an early stage of system development and proceeding as if we had only the kind of aggregate information on the reliability of the F-15 and the cost of its components that is typically available at such a stage. In addition to the average failure rate and cost of the components of the system, we assumed the availability of specific information on a small number of critical parts. We developed a set of disaggregation rules that (when applied to the aggregated F-15 data) yielded a fairly good approximation of the results we got using actual disaggregated data for the F-15. This exercise in simulating disaggregate data with aggregate data involved making assumptions about the joint distribution of the cost and the failure rate of components.

4. Analyzing the Advanced Tactical Fighter as an Example of the Method

The approach described in the preceding section is appropriate for analyzing the value of reliability in systems of traditional design in which all the components are attached in series and the failure of any component will cause the system to be unable to perform important aspects of its mission. The F-15 is such a system; the Advanced Tactical Fighter (ATF) is not.

In terms of reliability analysis, the avionics of the planned ATF differ from those of the F-15 in a number of important ways. The ATF avionics are being designed to achieve reliability and maintainability; the overall goal for the aircraft is to double the systems reliability of the F-15. If this goal is achieved, planners hope that the need for the avionics intermediate shop can be eliminated, and support costs substantially reduced. Because the ATF is still in the initial design stages, the aircraft has been used as a case example to test the methodology developed in this study.

In the new avionics architectures, redundancy is expected to extend beyond the usual flight control systems to include other systems, and some components may be reconfigurable. (Reconfigurability means that a single component can perform the functions of a number of other components--it performs the function that is needed.) Dyna-METRIC is capable of handling cases of redundancy but has not been adapted to handle reconfigurability.

Other features that will increase the availability of ATF include enhanced fault detection, improved fault isolation, and fewer connectors, which have traditionally posed problems. While historically the demand rates for parts in aircraft include false pulls, (occasions when a failure is reported but nothing is found to be wrong), the rate of such errors should be reduced in the ATF. Another design improvement in the ATF is in the area of fault isolation. In contemporary aircraft, a failed line replaceable unit (LRU) may contain both functioning and failed shop replaceable units (SRUs). In the ATF, isolating a fault to a single failed component at the flightline will often be possible, thus saving the cost of sparing for functioning components. Another feature planned for the ATF is using the systems built-in test features to direct aircraft to different bases at the end of sorties, depending on the type of maintenance needed.

This paper contains alternative methods of analyzing the value of reliability in such systems by altering the spare parts demand rates for the new system. More complex modeling methods are also sketched.

Appendix A contains a detailed description of the Dyna-METRIC model. (Also see Reference 2.) Appendix B discusses the issue of model validation--its ability to predict sortie generation in a combat setting--and describes the Coronet Warrier exercise, which indicated a correlation between Dyna-METRIC model results and actual exercise experiences. Appendix C describes the implementation of Dyna-METRIC on the Institute for Defense Analyses (IDA) computer. Appendix D discusses the development of the simulated data set. Appendix E contains a list of the F-15 LRU components used in this analysis.

II. MODELING THE VALUE OF RELIABILITY IN A CURRENT SYSTEM

A. USE OF DYNA-METRIC

The Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC) model is used by the Air Force to develop inventory requirements to meet specified levels of supply readiness (at minimum cost) and evaluate the readiness and sortie generation capability of aircraft as a function of logistic support (supply and maintenance) and operational considerations (such as flight scenarios and attrition rates).

Dyna-METRIC was selected for use in this study for the following reasons:

- It is capable of assessing the following determinants of readiness and sortie generation capability in an integrated fashion.
  - Reliability of aircraft components
  - Dynamic (fluctuating) flight hour programs
  - Dynamic logistic support availability (resupply cut-off and delayed intermediate-level maintenance support)
  - Aircraft attrition.
- It is flexible in terms of data requirements, making it suitable for use throughout the entire acquisition process. Dyna-METRIC can assess baseline reliability and maintainability, alternative aircraft configurations, logistics support characteristics, and force deployment strategies. As improved data on aircraft configuration, component reliability, component cost, maintainability, and logistic support structures become available, data bases can be easily modified for use in the model. While data quality improves, the evaluation technique remains constant. Better data improve the accuracy of model estimates, and use of the same model maintains consistency so that changes in results can always be related to data rather than to the peculiarities of models.
- It has become accepted by a large section of the Air Force community as a tool for evaluating logistic support in terms of sortie generation.
- It is used by the Air Force Logistics Command (AFLC) to determine inventory requirements (such as WRSKs) to meet readiness objectives.

- It is relatively easy to use. Data elements are transparent to decision makers, and model execution is relatively inexpensive and rapid.

Several other models were considered for use in our analysis. They fall into two classes, analytic or deterministic models and Monte Carlo simulation models.

Dyna-METRIC is an analytic model. This type of model uses established mathematical and statistical theory to develop functions that can estimate relevant support and operational statistics such as site back orders or fill rates and aircraft readiness or sortie success rates based on logistic support resource levels. These models are referred to as deterministic because of their reliance on formulas or equations. Other models that fit into this category are CACI's Availability Centered Inventory Model (ACIM), the Army's Selective Stockage for Availability, Multi-Echelon (SESAME) model, and the Center for Naval Analyses' Multi-Item, Multi-Echelon (MIME) model. All of these models have been used extensively in military analysis but differ from Dyna-METRIC in that they are steady-state models. Given initial resource levels and a logistic support structure, they assume that operating optempo and support are constant over a long period of time, and they provide evaluation of readiness at a point in time when the effect of support stabilizes.[1]

While all of these analytic models have specialized features that make them attractive for analyzing the effect of resource levels on capability, Dyna-METRIC was selected for use in the IDA study because it is capable of evaluating non-steady-state behavior--fluctuating operating tempo over a specified scenario and fluctuating logistic support associated with temporary cessations in resupply or repair capability.

Monte Carlo simulations can, in theory, replicate all of the operational and support concepts modeled by Dyna-METRIC. They are stochastic models that attempt to model every (programmed) operational, maintenance, and supply event of some scenario through assumed probability distributions and their parameters. In fact, they can model aircraft and support operations in much finer detail than Dyna-METRIC. For example, inflight operations, preflight aborts (and their causes), inflight aborts, and aircraft respotting, refueling, and rearming delays can be analyzed. In terms of maintenance and supply support, detailed manning levels, skills, and test bench configurations can be analyzed in terms of their impact on sortie generation capability or to identify bottlenecks in the logistic support network. Monte Carlo simulation models include the Naval Air Systems Command's Comprehensive Aircraft Support Effectiveness Evaluation (CASEE) model,

[1] Dyna-METRIC has a user option that allows steady-state evaluations.

the Naval Air Development Center's Simulation Package for the Evaluation by Computer Techniques of Readiness, Utilization, and Maintenance (SPECTRUM) model series, and the Air Force's Logistic Composite Model (LCOM).

Based on the study team's experience with these models, Dyna-METRIC was selected instead of the Monte Carlo models for use in this study for the following reasons:

- Dyna-METRIC captures the effect of the main areas of logistic support, flight operations, and aircraft parameters (reliability) as well as Monte Carlo simulations when the supporting data has the quality one would expect to gain through the acquisition process.
- Monte Carlo simulations are typically difficult to use, because they require massive data sets. During the acquisition process most of the detailed resource data available are not always accurate; thus the Monte Carlo models would yield results similar to the Dyna-METRIC model, which evaluates these support functions at a higher level. In any event, establishing the necessary data requires relatively large commitments in time and money, and the results will not surpass the quality of the Dyna-METRIC model output unless the accuracy of the data is guaranteed. The study team believes that this data quality will be relatively poor prior to Milestone III and is likely to remain so until shortly before the initial operational capability date for a system.
- Monte Carlo simulations are difficult to use because of computer and time requirements. Because of their stochastic nature, multiple evaluations of one scenario are necessary to estimate average performance statistics with some degree of certainty. A complete evaluation of one scenario using a Monte Carlo simulator could take weeks or months. The related computer costs are so great that using these models can become prohibitively costly.
- Dyna-METRIC can estimate the spare parts required to meet readiness targets at minimum cost. The Monte Carlo models can only evaluate sortie capability given a set of spares and have no easily executable provisions for estimating requirements.

Dyna-METRIC was selected instead of Monte Carlo simulations because it was judged to provide the same quality output (as related to problems of this study) as the Monte Carlo models, given the quality and the level of detailed data available during acquisition. Moreover, Dyna-METRIC is capable of producing more timely and cost-effective results.

1. What Dyna-METRIC Does

When supplied with LRU inventory levels, Dyna-METRIC simulates flight operations and resulting supply and maintenance responses. Unavailability of repair parts is recognized by the model as causing "holes" in aircraft (i.e., down aircraft). The Dyna-METRIC provision to allow component cannibalization is used for all LRUs (holes are consolidated). Cannibalization is not allowed for the pseudo-LRUs used to introduce maintenance (delay-LRUs) and battle damage.

Dyna-METRIC can then estimate the percentage of aircraft available at any point in the scenario. Using this information with the specified maximum number of sorties per aircraft per day, the model estimates the number of planned sorties that can be accomplished at each point in the scenario.

In this way, Dyna-METRIC can be used to evaluate logistic support in meeting a planned scenario. Note that inventory-level specifications must be made for each aircraft component in this analysis.

For the IDA study, Dyna-METRIC was also used to determine inventory requirements. Dyna-METRIC has an optimization routine that uses its evaluation methodology to select an inventory that will meet a readiness objective (a specified not-mission-capable rate due to supply) at minimum inventory cost. The inventories developed by Dyna-METRIC for this study were constructed using parameters similar to those that would typically be used by AFLC in inventory requirements development.

When appropriate, additional model features were developed by the study team to enhance the value of the model's output. (These features are briefly described in the following paragraphs and are detailed in II-B.)

The model has no direct provisions for modeling organizational maintenance delays and battle damage repair delays; however, the study team used Dyna-METRIC to include these factors in the analysis (also addressed in Section II-B).

When using the Dyna-METRIC attrition option, Dyna-METRIC assumes input operating tempo requirements apply to non-attrited aircraft only. For example, if a squadron has two aircraft, model input requires three sorties per aircraft per day and one aircraft is lost to attrition on day 1. On day 1, the aircraft are asked to fly six sorties, but on day two the model requires only three sorties.

Dyna-METRIC has a limited capability to assess the effect of scarce repair resources, such as test benches and manpower on spare part availability. Although the study team has not exercised this feature of the model in the analysis described here, this capability may be used in future evaluations of alternative support structures. If the user does not execute this constrained repair option, the model defaults to assuming infinite intermediate-level repair capability. (Under this model default, one can always assume inputted turnaround times (TATs) reflect support equipment availability. In this case, care must be taken to construct component TATs on this basis.) Regardless of the number of intermediate-level maintenance actions, average component TATs remain constant. In using the constrained repair option, the effect of queueing for scarce resources on pipeline size (or, equivalently, time to repair) is estimated, and the effect of increased pipelines on spare part availability and readiness is estimated by the model. (For a discussion of the limitation of the constrained repair option, see Reference 2.) While IDA has not executed this option during this study and thus cannot evaluate this option, evaluations of support equipment concepts may be possible during early stages of the acquisition process when logistic support is being postulated.

2. Limitations of the Model

Dyna-METRIC, like any model of this type, provides assessments of performance on the basis of assumptions made about the general operations of supply, maintenance, and sortie generation built into the model and the relevant data fed into the model. However, the model cannot, for example, take into account the ingenuity of supply and maintenance officers, all of the unobserved or unexpected conditions resulting from wartime operations, or the perturbations in average failure rates and repair times (from planned numbers) that cannot be foreseen. Dyna-METRIC does not model every nuance of aviation support. Nevertheless, it does model aircraft operations and supply and maintenance with sufficient accuracy and detail to allow managers to make effective decisions about support and design parameters for aircraft.

3. Data Required to Use Dyna-METRIC

Dyna-METRIC estimates the effects of logistic support on a planned operating scenario. In this study, we analyzed operations at one base and for one type of aircraft, the F-15C configured for the Pacific Air Force (PACAF). Assuming a specified level of rear-echelon support, Dyna-METRIC is capable of simultaneously analyzing multiple-site operations in a multi-echelon support network. The user must supply the following input to the model to define the planned operating scenario:

- Force levels (number of aircraft)
- Flying hour program
  - Number of sorties per day
    - -- Peacetime rate
    - -- Number per day for each day of the wartime portion of the scenario
  - Flight hours per sortie
- Attrition rates (separate rates can be specified for each day of the wartime portion of the scenario).

To analyze operations in terms of logistic support, each aircraft must be described in terms of its components (LRUs) and, if possible, the lower indentured components of the LRUs, (SRUs and sub SRUs). Analysis conducted in this study focused on LRUs. The following LRU factors are used by the model in analyzing the effectiveness of a logistic support system.[2]

- Aircraft configuration (a complete list of LRUs on the aircraft).
- Removal rate for each component (per flight hour or per sortie).
- Quantity of each LRU per aircraft
- Level of repair for each component (an indication of whether a component can be repaired on site or must be repaired at higher echelons of support, such as depots).
- Not-Repairable-This-Site (NRTS) rate for each LRU. This is the percentage of removals that must be condemned or sent to higher repair echelons because, for example, the site does not have complete repair capabilities.
- TAT for each LRU. This is the time it takes maintenance to return a failed part to a ready-for-issue state and should not be confused with the time it takes to remove a failed part from an aircraft and replace it with a working part.
- Resupply time for each LRU. This is the time it takes rear-echelon support to meet requirements for parts that fail and cannot be repaired on site.

In addition to these factors which Dyna-METRIC has been programmed to represent, the model was adapted to analyze the effects of battle damage and maintenance delay. (The discussion on how the model and data were used to analyze battle damage is

---

2 *If lower indentured parts are analyzed, similar factors must be supplied for the SRUs and sub SRUs.*

described in the following section) To take advantage of this customized option, the user must supply the following battle damage operating scenario parameters:

- Battle damage rate as the number of battle damage incidents per sortie,[3]
- Proportions of damage by cause.

4. Software Requirements

The version of Dyna-METRIC in use at IDA is AFLC's Version 4.4. This version was adopted because it is most consistent with Air Force calculations of WRSKs.

Graphic presentation of research results has been enhanced with the use of various off-the-shelf personal computer (PC) software packages. Results of Dyna-METRIC runs are downloaded to the PC. Data are manipulated in a spreadsheet and a presentation graphics package. The data are then available in a much wider variety of formats than provided by the VAX.

In addition to upgrading the VAX version of Dyna-METRIC, work was accomplished on acquiring and customizing a PC-based version of the model. The Dyna-METRIC Microcomputer Analysis System (DMAS) was designed by Dynamics Research Corporation for the Air Force for use as a unit-level logistic analysis tool for the Tactical Air Command (TAC). DMAS provides an expert user option that allows the user to run the PC Dyna-METRIC code independently from the other capabilities of DMAS (the menu system, data base system, and input file creation) that are more appropriate to field use. Appendix A contains additional details on the capabilities and revisions of Dyna-METRIC and DMAS.

B. DATA SOURCES AND MODELING METHODS

This section describes the F-15 data used to illustrate the use of Dyna-METRIC in analyzing aircraft reliability. They are presented in terms of the Dyna-METRIC input variables listed in the previous section.

---

3 Current IDA programming of this feature assumes battle damage rates are constant during the wartime scenario, but with additional computer time and analyst intervention, the model can evaluate variations in the battle damage rate.

1. Force Levels and Flying Hour Program

The Baseline analysis presented in this paper supporting 24 forward-deployed F-15C aircraft during a 30-day wartime scenario with a flying schedule as in Table II-1.

Table II-1. Baseline Wartime Flight Hour Program

Day of Scenario	Planned Sorties per Aircraft per Day	Flight Hours per Sortie	Total Planned Flight Hours per Day
1-3	3.13	2	150.2
4-6	3.09	2	148.3
7-19	1.00	2	48.0
20-29	.98	2	47.0
30	.97	2	46.6

We also analyzed more challenging sortie schedules. The moderate surge optempo schedule called for 100 flight hours per day for the post-surge period (days 7 through 30). The surge optempo schedule called for a full surge throughout the 30-day scenario.

Attrition rates (when used) were assumed to be 2 per 100 sorties attempted for days 1 through 6 of the scenario and 1 per 100 sorties for day 7 through 30.

Battle damage rates (when used) were assumed throughout the scenario to be 10 incidents per 100 sorties. A common benchmark used in analysis considers the level of battle damage to be approximately five times the level of attrition.

Recall that in this analysis, battle damage was modeled from a maintenance delay point of view, and the effect of the unavailability of repair material was not modeled. In particular, battle damage repair was modeled for eight areas of the aircraft. (See Table II-2.) Two types of battle damage were considered: damage from small arms fire and damage from high explosives. The probabilities of battle damage in each functional area (given a battle damage incident) assuming small arms or high explosive damage are given in Table II-2. All figures were based on combat damage on U.S. Air Force fighter aircraft involved in the Southeast Asia conflict as reported in II-3. Mean repair times for individual battle damage repair were also taken from data in II-1 and are contained in Table II-3.

In the analysis, the data in Tables II-2 and II-3 were used to describe the implications of the assumed number of battle damage incidents (10 incidents per 100 sorties) and an assumed split between small arms and high explosive battle damage. For the analysis presented in this report, we assumed a 50-50 split, but the model can easily examine any desired split of battle damage between small arms and high explosive threats.

Table II-2. Probability of Battle Damage by Type of Threat and Functional Area

F-15 Functional Area	Small Arms	High Explosive
Structure	.933	.927
Flight controls	.126	.182
Propulsion	.163	.225
Fuel	.153	.309
Power	.047	.309
Avionics	.140	.091
Crew station	.042	.073
Armament	.032	.055

Table II-3. Mean Battle Damage Repair Times by Type of Threat and Functional Area

F-15 Functional Area	Small Arms	High Explosive
Structure	8.4	21.3
Flight controls	30.6	27.7
Propulsion	17.8	157.3
Fuel	5.0	5.0
Power	35.0	652.2
Crew station	20.0	51.9
Armament	5.0	5.0

2. Logistic Support Scenario

Although the operating scenario remained constant in all of the analyses presented in this study, the following logistic support scenario was used as a baseline. Elements such as resupply times and intermediate-level maintenance capability were varied to test the sensitivity of results to these logistic parameters.

The baseline parameters for logistic elements were as follows:

- No resupply from rear-echelon support points during the 30-day scenario. Spare part inventories were designed to support 30 days of operations and were assumed to be on hand at the beginning of the scenario.
- Intermediate-level component repair capability varied by aircraft component:
  - Simple repair of Remove, Repair, and Replace (RRR) items (as designated by AFLC) could begin any time after day 4 of the scenario.

- More complex repair of Remove and Replace (RR) components (as designated by AFLC) could not be accomplished at all during the first 30 days. These items typically would be repaired at the depot.

Component repair capability varies because of requirements for support equipment and personnel. The classification of components into simple and complex repair categories is made on the basis of failure rates, mission criticality, and the amount of equipment needed to perform repair. The capability to perform organizational-level maintenance and battle damage repair was assumed to commence on day 1 of the scenario. When we included maintenance delay in the scenario, it was assumed to be 2 hours for each LRU.

3. Component Reliability and Maintainability Data

Baseline reliability and maintainability (R&M) data specifying LRUs of the F-15, LRU failure and NRTS rates, and LRU intermediate-level maintenance TATs were developed for PACAF WRSK components. Results of the analyses are based on the 387 LRUs of this data base as established by AFLC for spares requirements determination. (See Appendix D for a listing.)

Analyses of alternative aircraft reliability levels were carried out by scaling failure rate parameters of the R&M data base. For example, to analyze the effect of high reliability, the failure rate of each LRU in the data base was multiplied by 0.5.

4. Adaptation of the Model for Organizational-Level Maintenance Delay and Battle Damage

An important factor not programmed into Dyna-METRIC is organizational maintenance. The model was not designed to consider aircraft repair delays caused by organizational-level maintenance on aircraft. While the model does consider repair delay caused by supply support, it disregards the time it takes to remove and replace a part when a replacement spare part is available, which can cause the model to significantly overstate sortie generation capability. IDA has developed a technique to incorporate organizational maintenance into the model. To do so, the mean time to repair (MTTR) for each LRU must be specified. This is the time it takes organizational maintenance to remove a failed part, acquire a replacement from supply (assuming a replacement is in stock), and install the ready-for-issue part on the aircraft.

IDA's modifications of Dyna-METRIC to include battle damage and organizational-level repair time analyses (maintenance delay) and battle damage analyses are through Dyna-METRIC's modeling of LRUs.

Aircraft downtime due to organizational-level repair is modeled by constructing a pseudo-LRU for each LRU in the data base. Each pseudo LRU has the same failure rate and quantity per aircraft as its associated LRU. The objective is to have a pseudo LRU fail whenever the corresponding LRU fails. The NRTS rate for the pseudo LRUs are always assumed to be 0--the pseudo LRUs must always be repaired at the organizational level by some specified time, the TAT. By assuming the pseudo LRU stock level to be zero, an organizational-level maintenance delay will occur each time an LRU fails. This delay can be customized to each LRU or can be applied to all LRUs. For illustrative purposes, we have assumed a two-hour delay. Delays in aircraft repair due to battle damage are similarly modeled. Currently, eight functional areas of the aircraft are designated as battle damage LRUs. Failure rates (battle damage rates) are specified for each area. A MTTR is specified and used with battle damage LRUs so that the model simulates battle damage repair and its associated downtime .[4]

5. Adaptation of the Model for Sortie Goal with Attrition

Two inputs for Dyna-METRIC are operating tempo (as sorties per aircraft per day) and attrition (as a percentage per sortie). These two inputs are related in the sense that the sortie rate objective is viewed by the model as an objective for non-attrited aircraft only. One analysis carried out by the study team was evaluating the capability of a squadron to meet a sortie schedule, independent of attrited aircraft. Early run of the model made it clear that Dyna-METRIC does not attempt to fly a full sortie schedule when there are attrited aircraft. Therefore, we developed a method to allow Dyna-METRIC to handle a full sortie schedule with attrition. The following example illustrates how Dyna-METRIC input is adjusted to analyze an attrition problem. Suppose a squadron of 25 aircraft is scheduled to fly 50 sorties per day for 10 days with an attrition rate of 1 aircraft per 100 sorties. Table II-4 reflects how Dyna-METRIC input is scaled to analyze this schedule.

---

[4] Analyzing battle damage by component would require that LRU failure rates, MTTRs, TATs and NRTS rates be adjusted to reflect battle damage. Data are insufficient for this detailed analysis at present.

Table II-4. Example Method of Optempo Adjustment in Attrition Case

Day	Number of Nonattrited Aircraft	Planned of Sorties	Sorties per A/C per Day
1	25	50	2.00
2	25	50	2.00
3	24	50	2.08
4	24	50	2.08
5	23	50	2.17
6	23	50	2.17
7	22	50	2.27
8	22	50	2.27
9	21	50	2.38
10	21	50	2.38

Prior to model execution, a daily squadron sortie schedule was developed for analysis. Based on this schedule and the attrition rates that were to be analyzed, the daily number of non-attrited aircraft were computed. Using the daily numbers of attrited aircraft and the desired daily sortie schedule, the number of sorties per non-attrited aircraft were computed for each day of the scenario. This sortie schedule and the assumed attrition rate were entered into Dyna-METRIC to guarantee an analysis of the desired sortie goal for each day of the scenario.

C. EMPIRICAL RESULTS

This section contains results of computer runs using F-15C data and the Dyna-METRIC model to demonstrate how changes in system reliability affect sortie generation and the cost of spares. The following baseline assumptions were made:

- Sortie program with surge in first six days (see Table II-1 for details).
- RRR repair beginning on day 5, no RR repair during the scenario.

Our process of analysis was to

- Buy spares to achieve this baseline scenario, at three levels of reliability
- Analyze the cost of these spares
- Study alternate wartime scenarios by varying the assumptions about attrition, battle damage, and maintenance delay. In each case, begin with sufficient spares to achieve the flying program, under baseline conditions, at each level of reliability. Determine how well the squadron does with these spares packages in each excursion
- Evaluate the total sorties achieved in each excursion and compare to the baseline

- Investigate the effect of more challenging sortie schedules using the same spares packages and a set of variations similar to those used in the initial scenarios
- Calculate the spares cost per sortie for every scenario.

In each case, increased reliability allows the squadron to achieve more sorties. This is always true during the initial surge period, a crucial time of the conflict, and usually true during the last 24 days of the scenario, when only one sortie per aircraft per day is required. Diminished reliability decreases the percentage of the flying program achieved and also increases the cost of spares.

1. Assessing the Cost of Sparing Under Different Reliability Levels

The first step in the analysis was to determine the spare parts packages required to achieve the flying program under the baseline assumptions and the three reliability levels. We did not try to run each variation with equal spare parts packages regardless of failure rates. Rather, we consistently used spares packages that allow the flying program to be achieved under baseline conditions, reflecting Air Force practice. We did not spare to individual scenarios, only to the flying program under baseline conditions. The aggregate cost of the total consumption of these spares was determined, leading to the calculation of the cost of spares for each reliability level. As expected, the costs of the spare parts packages are substantially different under the three reliability assumptions (See Table II-5.)

Table II-5. Baseline Spares Costs

Level of Reliability	Spares Cost	Baseline Spares Cost per Sortie
Normal (AFLC demand rate)	$69,406,000	$68,200
High (.5 times normal demand rate)	$30,396,000	$29,900
Low (1.5 times normal demand rate)	$106,469,000	$104,600

Increased reliability dramatically lowered the spares costs of the baseline flight program. The cost benefits resulting from increased reliability yielding lower spares costs occurred in every scenario studied. The spares costs listed in Table II-5 were used to calculate the spares cost per sortie for each scenario. Further analysis of the spares cost per sortie is included in Chapter II, section C.4.

2. Assessing the Effect of Reliability on Sortie Generation Capability Under Differing Wartime Conditions

Figure II-1 shows the sortie program for the analysis--a 30-day scenario with a surge in the first six days. We evaluated the ability of the squadron to fly the sortie program under the following sets of conditions:

- Organizational-level maintenance delay of two hours for each failure, an approximation of the time required to diagnose and fix the problem.
- Attrition of two percent per sortie during the surge and one percent thereafter, along with maintenance delay.
- Battle damage of ten percent per sortie, along with attrition and maintenance delay.

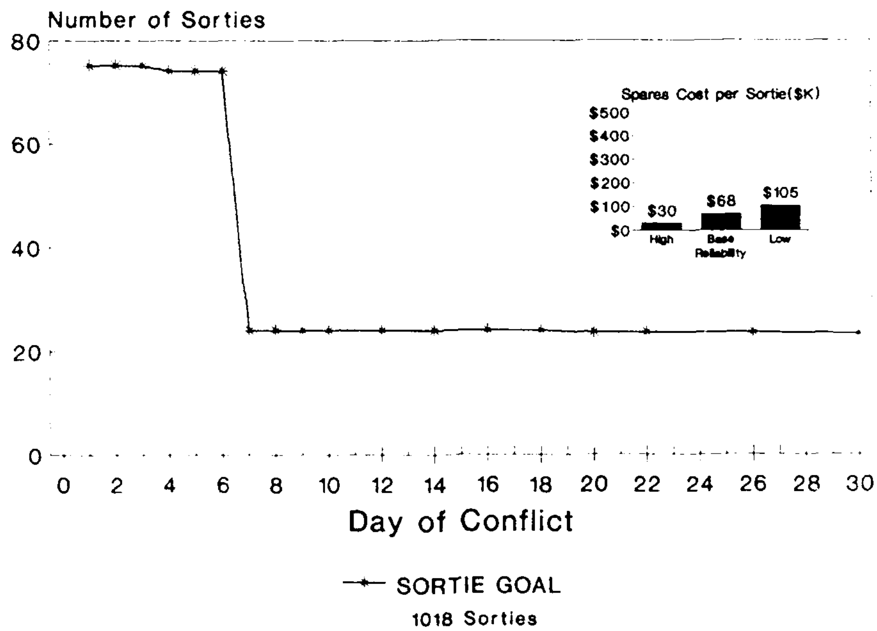


Figure II-1. F-15C Baseline Sortie Program

The line charts in Figures II-2 through II-4 and the data in Table II-6 and Figure II-5 summarize the sortie generation results. The figures show the number of sorties achieved on each day and at each level of reliability in comparison with the baseline sortie goal. The table shows the cumulative number of sorties achieved by day 6 and by day 30. (Since the Dyna-METRIC model does not generate data for each day of the 30-day flying period after day 10, the numbers of sorties achieved on these days were interpolated from the given data. These values were included in the total number of sorties calculated at each reliability level for every scenario studied.)

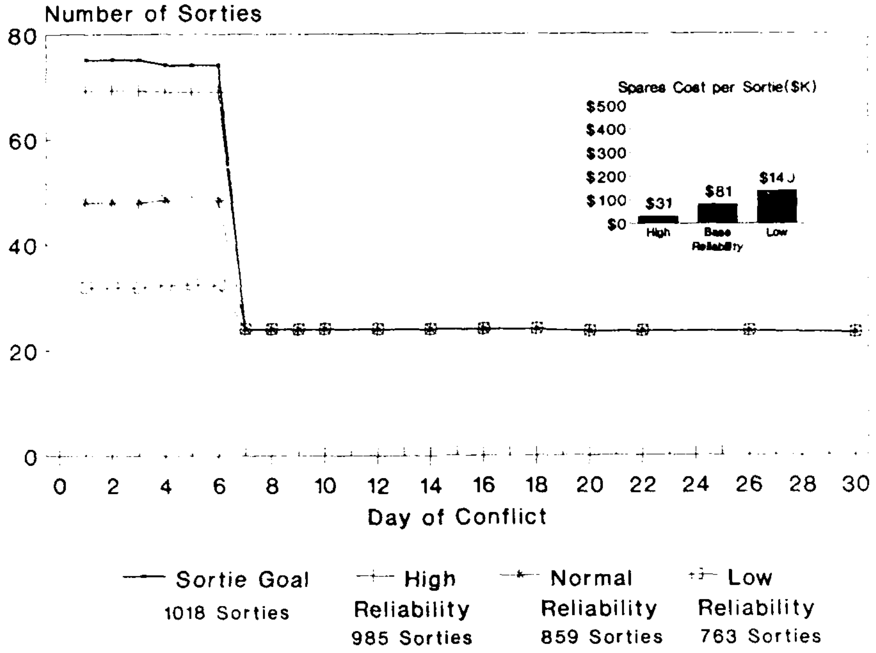


Figure II-2. Number of Sorties Achieved in the Maintenance Delay Case

Organizational-level maintenance delay does affect sortie generation during the initial six-day surge, as can be seen in Figure II-2. While nearly all sorties are achieved in the high-reliability case, approximately 67 percent of the sorties are achieved during the surge in the normal-reliability case, and 43 percent of the sorties are achieved in the low-reliability case. Combat-like conditions need not be introduced to demonstrate that reliability produces greater benefits than are identified in the Air Force's provisioning analysis, which does not incorporate repair time.After the first six days, all sorties are achieved in all cases.

Adding attrition to the maintenance delay excursion dramatically affects sortie generation during the initial six-day surge (see Figure II-3). During the surge, the percent of sorties achieved falls to 74 percent by the end of day 6 in the high-reliability case, 46 percent in the normal-reliability case, and 29 percent in the low-reliability case. During the last 24 days, small performance differences exist between the normal and low-reliability cases.

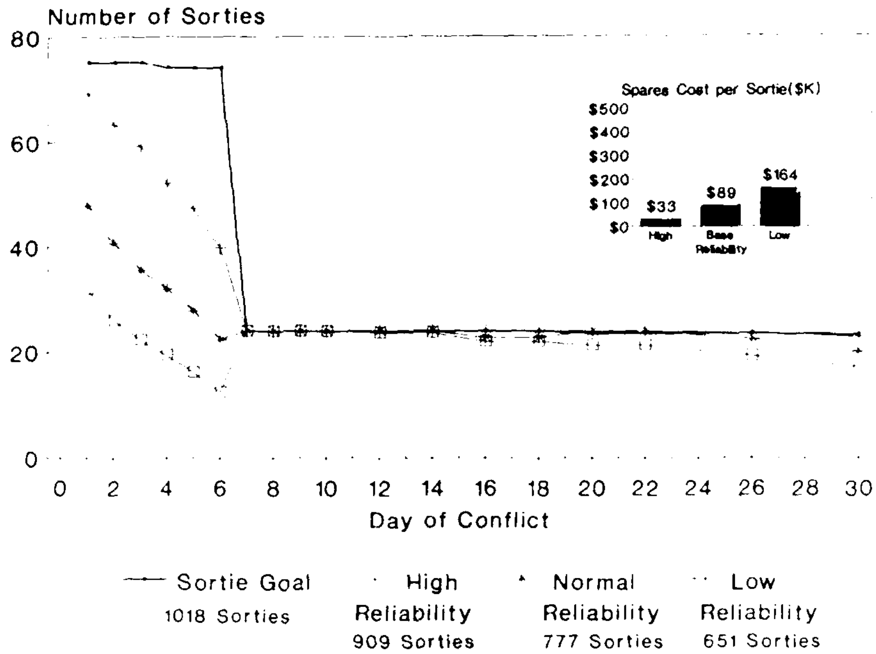


Figure II-3. Number of Sorties Achieved in the Maintenance Delay/Attrition Case

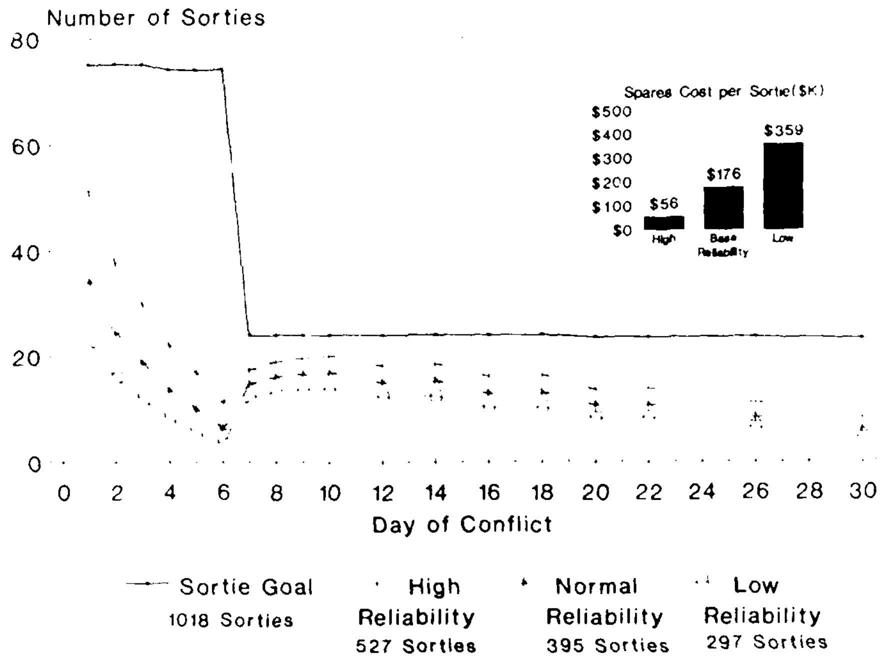


Figure II-4. Number of Sorties Achieved in the Maintenance Delay/Attrition/Battle Damage Case

Table II-6. Number of Sorties Flown Under Baseline Conditions and Varying Levels of Reliability

	After 6 Days		
	High	Normal	Low
Baseline	447.72	447.37	446.58
Maintenance Delay	414.82	289.01	192.75
Maintenance Delay and Attritition	330.96	206.14	128.11
Maintenance Delay, Attrition and Battle Damage	169.14	106.99	67.69
	After 30 Days		
	High	Normal	Low
Baseline	1017.60	1017.25	1016.46
Maintenance Delay	984.70	858.89	762.63
Maintenance Delay and Attrition	908.83	776.78	650.98
Maintenance Delay, Attrition, and Battle Damage	527.18	395.29	296.69

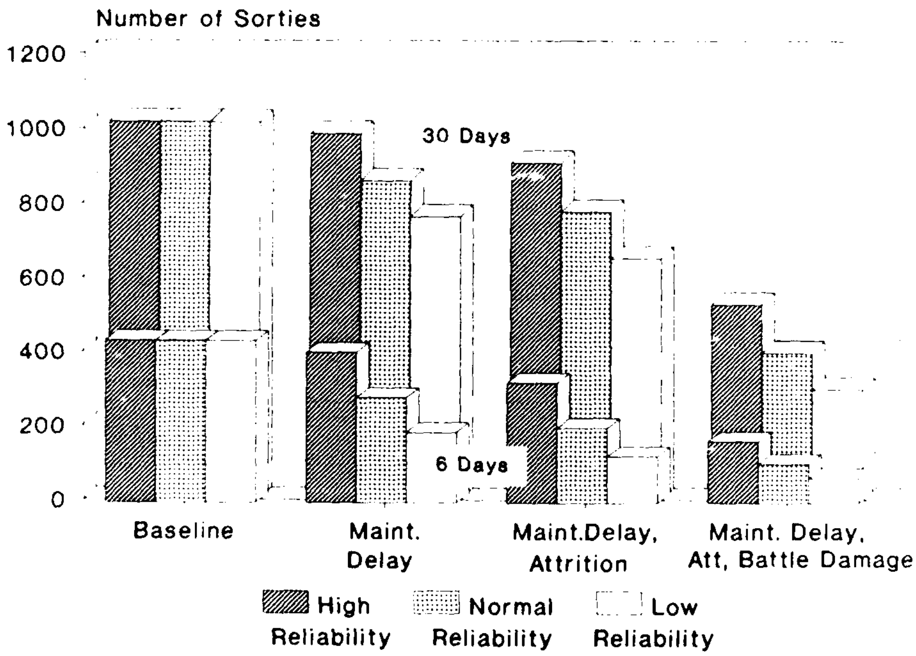


Figure II-5. Number of Sorties After 6 Days and After 30 Days Under Various Baseline Scenarios

The case combining battle damage, attrition, and maintenance delay (see Figure II-4) resulted in considerable deterioration in sortie achievement from the preceding cases. By the end of day 6, only 24 percent of sorties could be flown in the normal-reliability case. Reliability made a major difference in the sorties achieved during the surge period. At the end of the 6-day surge, 38 percent of sorties were flown in the high-reliability case, and only 15 percent in the low-reliability case. Reliability continued to play a noticeable role in the number of sorties achieved throughout the last 24 days. In the high-reliability case, 130 more sorties were achieved than in the normal-reliability case over the 30-day period. Overall results for the entire 30-day period under this scenario show that 52 percent of the sorties can be achieved in the high-reliability case as compared to 39 percent in the normal-reliability case and 29 percent in the low-reliability case. (A summary of the percent of the sortie goal achieved under each scenario is presented in Table II-7.)

Table II-7. Percent of Sorties Flown Under Baseline Conditions and Varying Levels of Reliability

	High	Normal	Low
Maintenance Delay (Sortie goal 1,018)	97	84	75
Maintenance Delay and Attrition (Sortie goal 1,018)	89	76	64
Maintenance Delay, Atrition, and Battle Damage (Sortie goal 1,018)	52	39	29

Figure II-5 graphically reiterates the data listed in Table II-6 The front group of bars represents the cumulative number of sorties flown after 6 days and the back group of bars shows the number of sorties flown after 30 days.

3. *Sortie Generation Under More Challenging Sortie Schedules*

Because IDA research results indicated the value of reliability in a wartime scenario, we pursued additional excursions with more severe constraints. We investigated both surge optempo and moderate surge cases under the following conditions using the same parameters as the wartime scenarios:

- No maintenance delay, no attrition, no battle damage
- Maintenance delay only
- Maintenance delay, attrition, and battle damage.

The following assumptions were made for both the surge optempo and the moderate surge:

- 24 aircraft squadron
- 30-day flying program
- 2-hour sorties per aircraft
- Cannibalization permitted

- 3 demand rate levels
- Severe sortie schedules
  - Surge optempo
    - - 75 sorties per day for days 1 through 30
  - Moderate surge
    - - 75 sorties per day for days 1 through 6
    - - 49 sorties per day for days 7 through 30.

With these sortie schedules, the sortie goals increase. In the surge optempo case, the sortie goal is 2,253; in the moderate surge case, the goal is 1,649. Since the demands are now greater, the model tries to meet those higher demands. In some of the surge scenarios, therefore, more sorties are achieved than in the baseline flying program.

Figures II-6 and II-7 and Tables II-8 and II-9 provide additional evidence of the value of reliability on the sortie generation rates under the least stringent (no maintenance delay, no attrition, no battle damage) of these challenging situations. In the moderate surge scenario, the percent of the sorties achieved in the high-reliability case was 98 as opposed to 79 and 62 in the normal and low-reliability cases, respectively. Approximately 300 more sorties were completed at each successively higher reliability level. In the surge optempo scenario, the percent of sorties achieved was about half that achieved in the corresponding reliability level under moderate surge (high 59 percent, normal 37 percent, low 30 percent). The value of increased reliability is consistently evident throughout both scenarios.

The results in the surge optempo case require some explanation. As can be seen in Figure II-7, in both the low and normal-reliability cases, after a certain point, no additional sorties are flown. This is attributable to the fact that at no time in the 30-day scenario do we have RR repair capabilities. In addition, no transportation component is built into the Dyna-METRIC model. Therefore, if initial spares are completely depleted, resupply is not possible. Since this particular scenario does not include attrition, one concludes that after a certain point, so many components are not repairable that no further sorties can be flown.

Figures II-8 and II-9 and Tables II-8 and II-9 present the results of the severe study cases with maintenance delay only. The moderate surge scenario results again indicate the value of reliability. In the high-reliability case, 96 percent of the sorties can be achieved, continuing with 69 percent in the normal and 44 percent in the low-reliability case. These results are consistent with those of the baseline flying program with maintenance delay. In the surge optempo scenario, sortie achievement drops rather drastically from the sortie goal. The number of sorties achieved actually falls to zero after day 22 in the normal-reliability case and after day 16 in the low-reliability case. These results are similar to the surge optempo results in the least stringent severe case described in the preceding paragraph. In reality, if either severe scenario occurred and measures were undertaken to appropriately compensate for attrition and battle damage, a moderate number of sorties could be achieved.

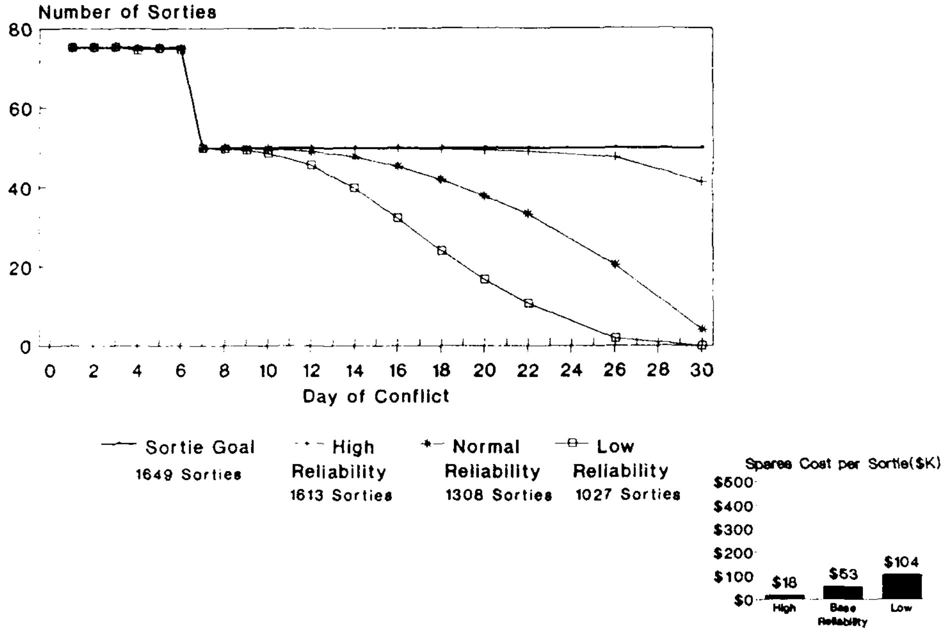


Figure II-6. Number of Sorties Achieved Under Moderate Surge - No Maintenance Delay, No Attrition, No Battle Damage

It can be observed that more sorties are achieved at each reliability level in the moderate surge case than in the surge optempo case. These results might imply that more sorties can be achieved by requiring less. However, since fewer sorties are required after day 6 in the moderate surge case, there is more time between sorties and the maintenance delay has less effect than it does under surge optempo. It should also be recalled that planes are being lost more rapidly in the surge optempo case because we are attempting to fly more sorties to meet the higher sortie goal.

Figures II-10 and II-11 and Tables II-8 and II-9 summarize the results of the scenarios with the most severe constraints, moderate surge and surge optempo with maintenance delay, attrition, and battle damage. In the moderate surge, the percent of sorties achieved at the high-reliability level is only 34, followed by 25 for the normal-reliability case and 18 for the low- reliability case. Sortie achievement under the surge optempo varies from 16 for high reliability, 10 for normal, and 7 for low. Although these are not very positive results, flying a reasonable number of sorties during the first six days is possible, if they are absolutely necessary. The value of reliability is consistently observable in all of the severe cases described here.

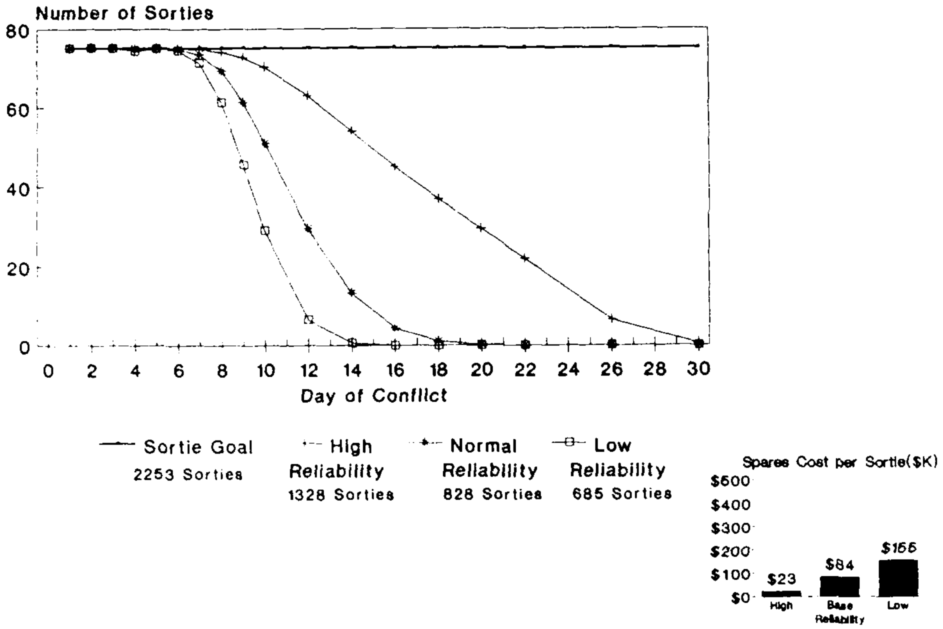


Figure II-7. Numbers of Sorties Achieved Under Surge Optempo - No Maintenance Delay, No Attrition, No Battle Damage

Figure II-12 summarizes the results of one last excursion. In all previous scenarios, RRR repair began on day 5. In this case, RRR repair does not begin until day 10. In all other ways this excursion is analogous to that represented in Figure II-7--surge optempo with no maintenance delay, no attrition, and no battle damage. Rapid degradation in sortie achievement starts occurring after day 4. The degradation is severe in this case with sorties falling to zero at the low-reliability level on day 8, before RRR repair has even begun. The slight increase in the normal and high-reliability cases at day 10 illustrates the introduction of RRR repair on this day. This particular scenario markedly represents the value of reliability, with 46 percent of the sorties achieved at the high-reliability level.

Table II-8 Number of Sorties Flown under Surge Scenarios

	After 6 Days		
Moderate Surge -no Maintenance Delay, no Attrition, no Battle Damage	450.57	450.13	449.21
Surge Optempo-no Maintenance Delay, no Attrition, no Battle Damage	450.57	450.13	449.21
Moderate Surge-Maintenance Delay Only	415.37	287.54	191.23
Surge Optempo - Maintenance Delay Only	415.37	287.54	191.23
Moderate Surge - Maintenance Delay, Attrition, and Battle Damage	195.73	130.36	86.66
Surge Optempo - Maintenance Delay, Attrition, and Battle Damage	195.73	130.36	86.66
Surge Optempo - RRR on Day 10	448.46	431.68	399.17
	After 30 Days		
Conditions	High	Normal	Low
Moderate Surge - no Maintenance Delay, no Attrition, no Battle Damage	1613.21	1307.95	1026.88
Surge Optempo - no Maintenance Delay, no Attrition, no Battle Damage	1327.88	827.63	684.93
Moderate Surge - Maintenance Delay Only	1578.00	1137.34	722.96
Surge Optempo - Maintenance Delay Only	1261.96	581.42	327.12
Moderate Surge - Maintenance Delay, Attrition, and Battle Damage	562.21	412.99	302.83
Surge Optempo - Maintenance Delay, Attrition, and Battle Damage	358.27	232.80	149.16
Surge Optempo - RRR on Day 10	1034.73	493.06	408.01

Table II-9. Percent of Sorties Flown under Surge Scenarios

Conditions	High	Normal	Low]
Moderate Surge - no Maintenance Delay, no Attrition, no Battle Damage (Sortie goal 1,649)	98	79	62
Surge Optempo - no Maintenance Delay, no Attrition, no Battle Damage (Sortie goal 2,253)	59	37	30
Moderate Surge - Maintenance Delay Only (Sortie goal 1,649)	96	69	44
Surge Optempo - Maintenance Delay Only (Sortie goal 2,253)	56	26	15
Moderate Surge - Maintenance Delay, Attrition, Battle Damage (Sortie goal 1,649)	34	25	18
Surge Optempo - Maintenance Delay, Attrition, Battle Damage (Sortie goal 2,253)	16	10	7
Surge Optempo - RRR on Day 10 (Sortie goal 2,253)	46	22	18

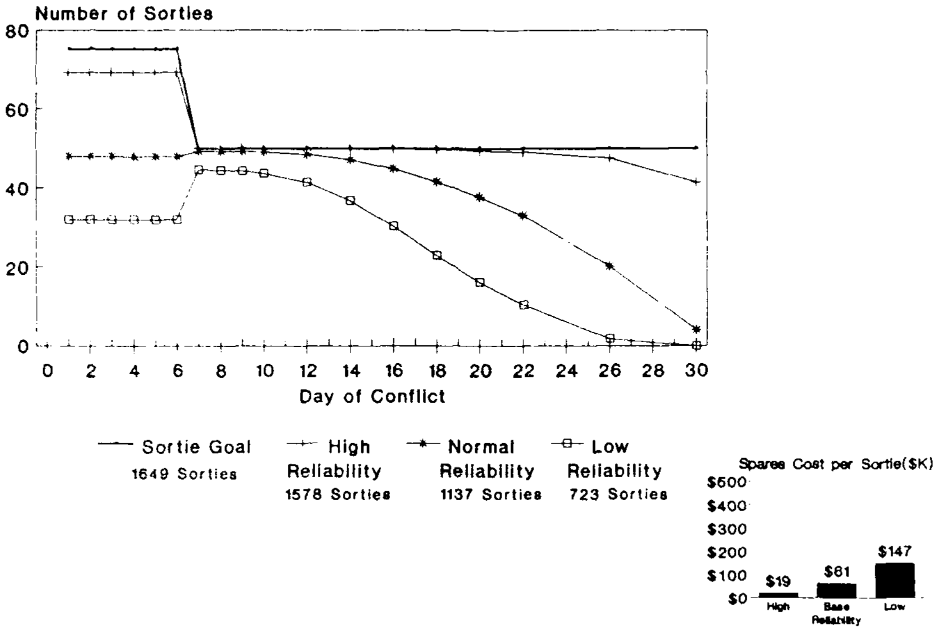


Figure II-8. Number of Sorties Achieved Under Moderate Surge - Maintenance Delay Only

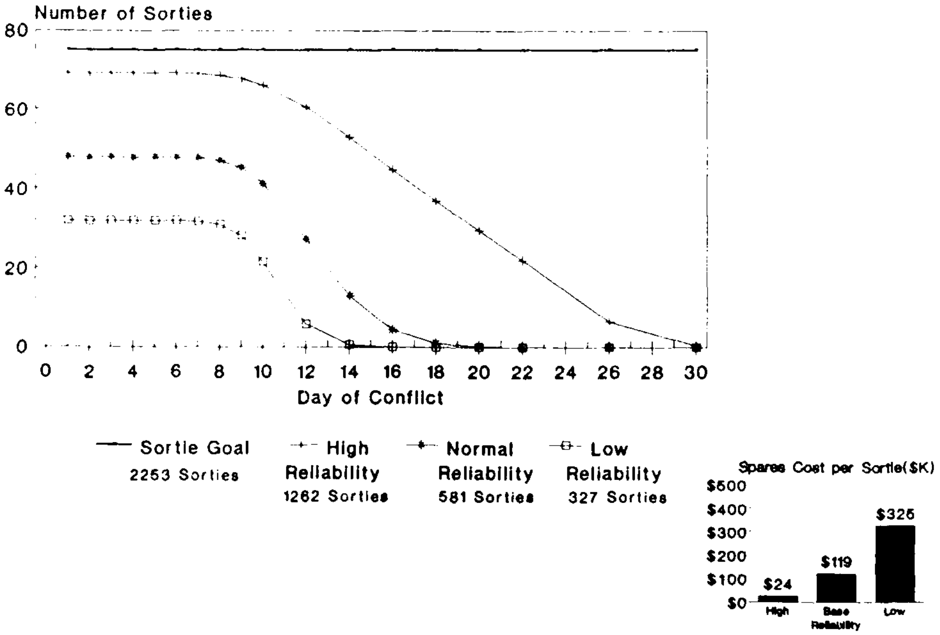


Figure II-9. Number of Sorties Achieved Under Surge Optempo - Maintenance Delay Only

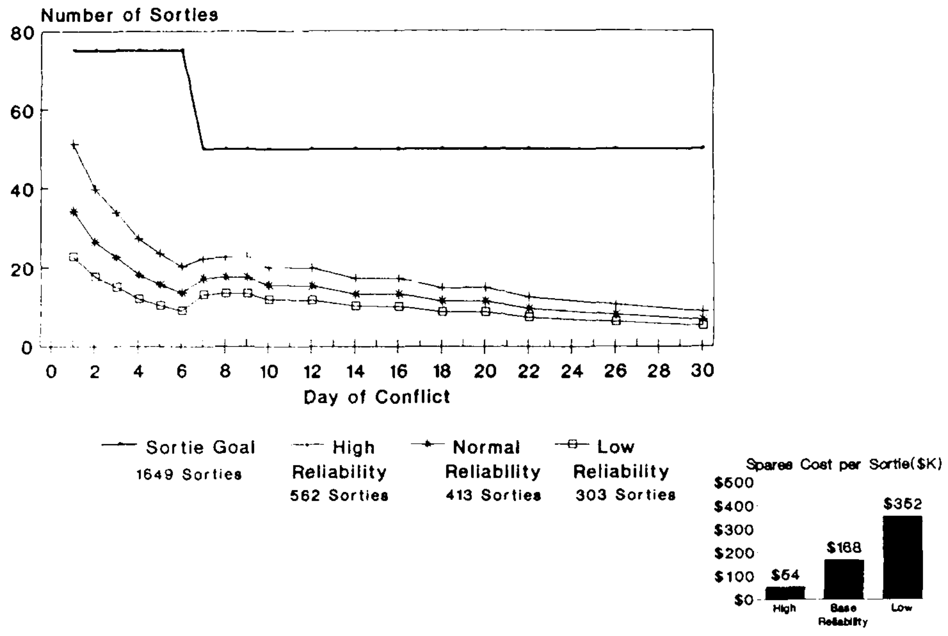


Figure II-10. Number of Sorties Achieved Under Moderate Surge - Maintenance Delay/Attrition/Battle Damage

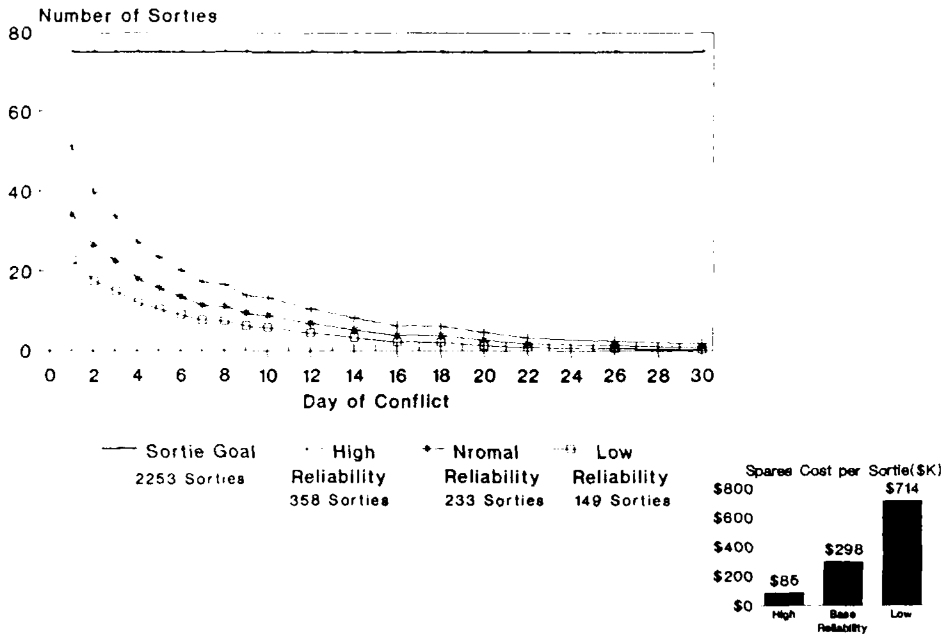


Figure II-11. Number of Sorties Achieved Under Surge Optempo - Maintenance Delay/Attrition/Battle Damage

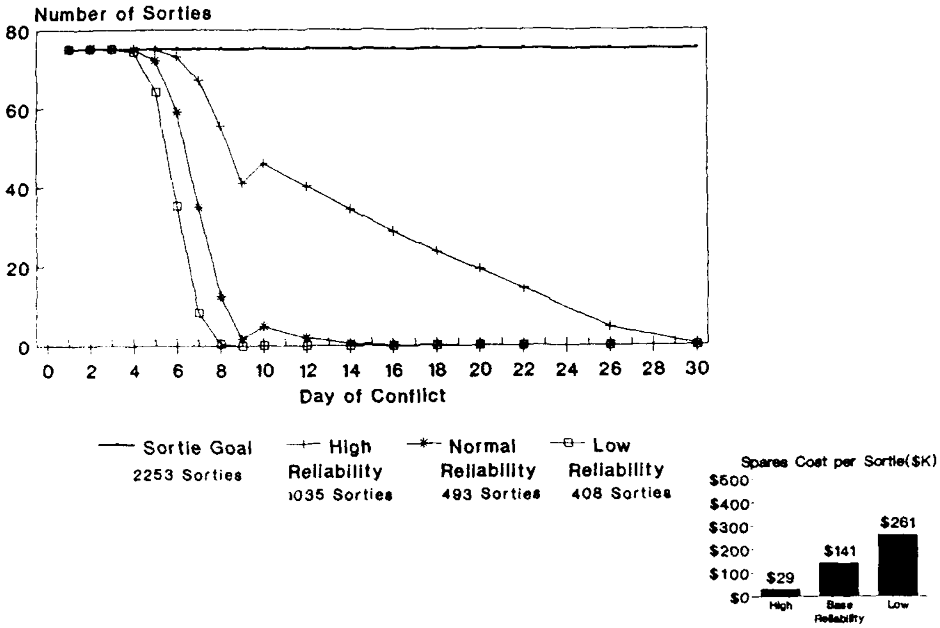
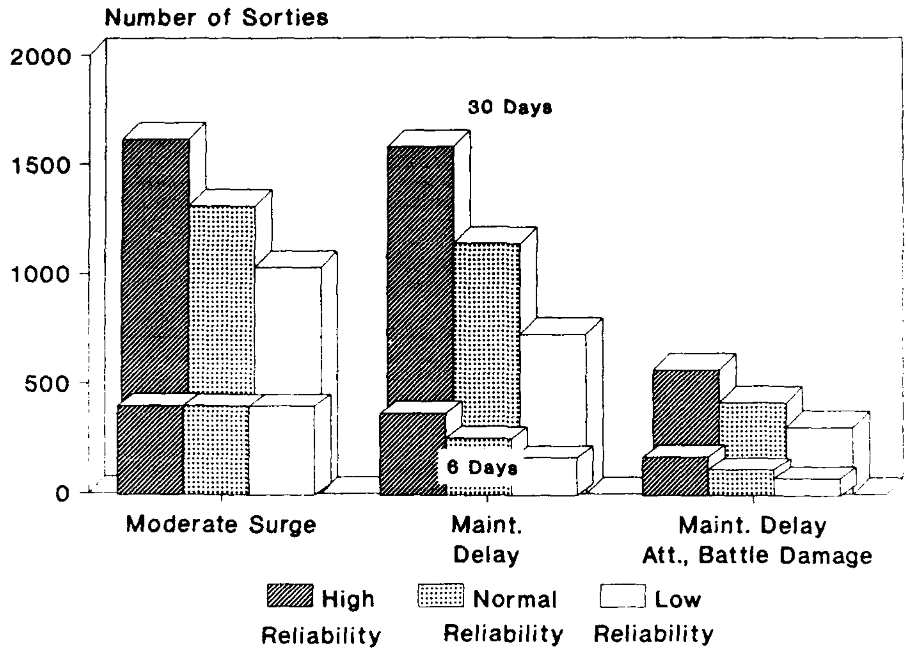


Figure II-12. Number of Sorties Achieved Under Surge Optempo with RRR beginning on Day 10

Figure II-13 graphically reiterates the data listed in table II-8. The top chart represents the number of sorties achieved in the moderate surge scenarios. The lower charts shows the same for the various severe surge scenarios. In each chart, the front group of bars represents the cumulative number of sorties flown after 6 days and the back group of bars shows the number of sorties flown after 30 days.

4. Assessing the Spares Cost per Sortie Under Differing Conditions

The spares cost per sortie was chosen as one measure of the effect of reliability on the cost of the flying program. Calculations for the spares cost per sortie were based on the spares costs listed for the three reliability levels in Chapter II, section C.1. The spares cost per sortie was computed by dividing the spares cost of a given reliability level by the number of sorties achieved at that reliability level for each study case. The bar charts in Figures II-1 through II-4 and Figures II-6 through II-12 summarize the spares cost per sortie.



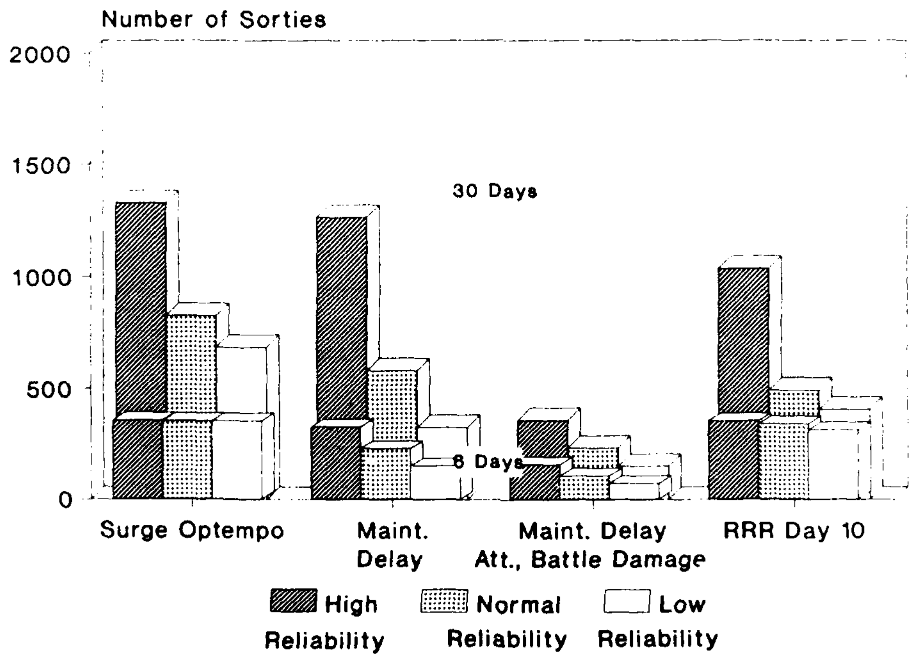


Figure II-13. Number of Sorties After 6 Days and After 30 Days Under Moderate Surge and Surge Scenarios.

With each set of conditions, the level of reliability makes a substantial difference in the spares cost per sortie. In the high-reliability cases, spares cost per sortie is from 62 to 68 percent less than the spares cost per sortie in the normal-reliability cases. Even greater disparity exists between spares cost per sortie of the normal and low-reliability cases. The low-reliability costs are from 70 to 104 percent greater than the normal-reliability costs. The spares cost per sortie increases at every reliability level as each scenario becomes more demanding. Table II-10 summarizes all spares costs per sortie.

Table II-10. Spares Cost per Sortie ($K) Under Different Conditions and Varying Levels of Reliability

	Level of Reliability		
	High	Normal	Low
Base Case	29.87	68.18	104.56
Maintenance Delay	30.87	80.81	139.61
Maintenance Delay and Attrition	33.44	89.35	163.55
Maintenance Delay, Attrition and Battle Damage	57.66	175.58	358.86
Moderate Surge - no Maintenance Delay, no Attrition, no Battle Damage	18.84	53.07	103.68
Surge Optempo - no Maintenance Delay, no Attrition, no Battle Damage	22.89	83.86	155.45
Moderate Surge - Maintenance Delay Only	19.26	61.03	147.27
Surge Optempo - Maintenance Delay Only	24.09	119.37	325.48
Moderate Surge - Maintenance Delay, Attrition, Battle Damage	54.06	168.06	351.58
Surge Optempo - Maintenance Delay, Attrition, Battle Damage	84.84	298.14	713.82
Surge Optempo - RRR on Day 10	29.38	140.77	260.95

5. Conclusions

In summary, the IDA study has indicated in a variety of ways that increased reliability produces higher sortie achievement rates and lower spares costs per sortie whether it be in wartime scenarios, under more challenging sortie schedules, or when constrained by a variety of conditions.

III. MODELING RELIABILITY IN A NEW SYSTEM

This section contains a discussion of generic issues involved in evaluating the reliability of a new system and describes the method used by the IDA study team to simulate data for evaluating the reliability of a new system. Specific issues regarding new avionics architectures are reviewed, and possibilities for evaluating the value of reliability in the new advanced tactical fighter are also discussed.

A. CONTEXT AND RELEVANCE

A main objective of this analysis is to develop a method for evaluating the value of increased system reliability for new systems, early in the design stage when reliability levels can be relatively easily changed. In adition to evaluating the value of system reliability, the office of the Secretary of Defense must determine whether the maintenance concepts for new systems are consistent with the mission requirements for example, determining whether a 3.2 hour mean time between failures (MTBF) is consistent with a four-sortie-per-day requirement. To make these decisions, a review is conducted at the subsystem level, usually at Milestone 1 and no later than Milestone 2. If the maintenance concept for a system is not consistent with mission requirements, then OSD works with the relevant Service to change the requirements.

In evaluating the reliability of a new system, many issues must be addressed. The program office usually sets the goals for system and subsystem reliability and the cost limitations for the system and subsystem. The program office also sets the plans for system maintenance.

The evaluator must then decide whether the goals set by the program office are reasonable and if achievement of the goals will ensure adequate mission performance. The evaluator must also determine whether the maintenance concept, given the goals, is the most cost-effective method, consistent with mission requirements (Reference 5 illustrates an approach to assessing the cost of building in reliability.)

Answering these questions about a new system presents a considerable challenge. With a new system, information on costs of components and the potential failure rates is often quite limited, and the architectures are only vaguely specified.

Therefore, evaluating a maintenance concept can be extremely difficult. Three factors affect the evaluation process:

- Level of data available. At a very early point in the program, data might consist of only the number of modules, the average cost, and the average failure rate systemwide. Later, data might consist of this information along with specific data on high-cost, high-failure-rate items and some indication of the differences among airframe, engine, and avionics. In even later stages of the program, the data would include specific information on all of the modules.
- Subsystems considered. As the progam matures, we would move from a broad analysis of the entire aircraft, to some detail at the subsystem level, a complete specification.
- Scope of costs considered. Currently, we are considering mainly spares costs at a preliminary level. In the future, we hope to include a broad analysis of manpower and support equipment costs. A more complete analysis would model these costs in greater detail.

The method we have developed here represents a beginning. A preliminary evaluation of the value of reliability in a new system can be done with knowledge of only the mean cost, mean failure rate, and number of modules. This method, along with a consideration of unique architecture issues, is a significant step toward reaching a methodology for a complete, thorough evaluation.

B SIMULATED DATA -- A STEP TOWARD EVALUATING NEW SYSTEMS

As a first step in using the model to analyze reliability in new systems, we examined how new systems could be evaluated using incomplete data. Figure III-1 depicts the methodology that we developed. The key step in the methodology is the development of a simulated data base to represent the new system. Available data on the distribution of the costs and failure rates of modules for the new system are combined with information on the joint distribution of costs and failure rates for existing systems of a similar kind.

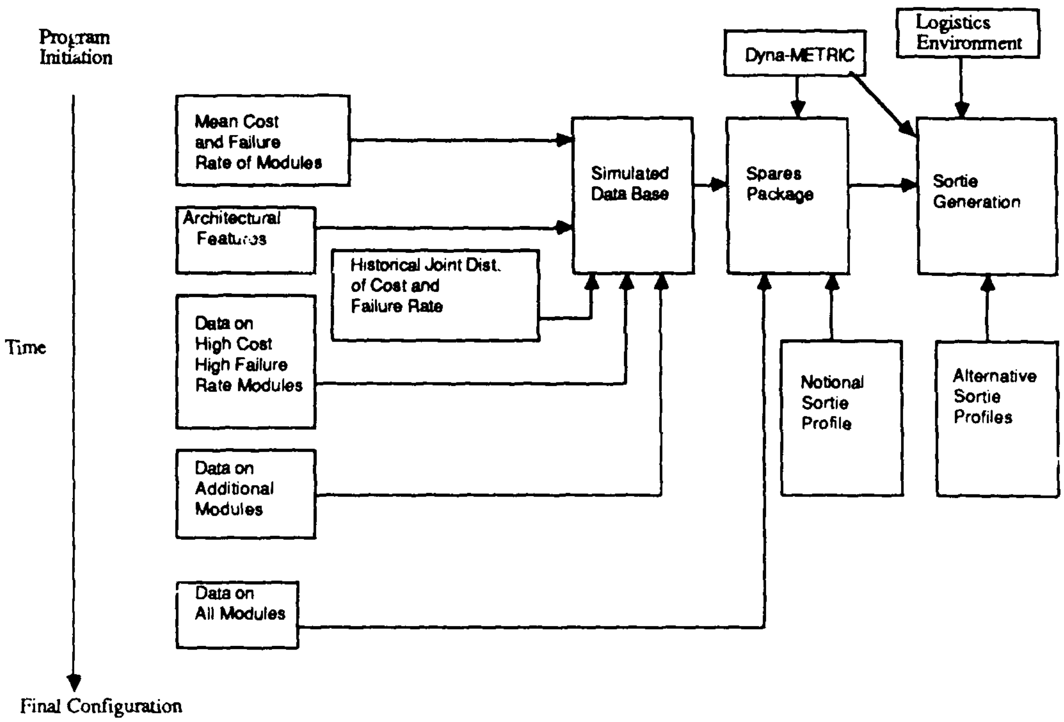


Figure III-1. A Methodology for Evaluating New Systems

When only mean costs and failure rates are known, the entire data set is simulated. As more information about the cost and reliability characteristics of individual parts becomes known, these parts are incorporated into the data base. The rest of the modules in the system are simulated in a way that keeps aggregate system parameters consistent with what is believed about the average cost and failure rate and with the hypothesized joint distribution. Information about critical architectural features of the new system (such as the extend of redundancy among modules) can also be incorporated. As the full configuration of the new system becomes known, the methodology approaches a standard application of Dyna-METRIC.

The simulated data base is used in exactly the same way we used F-15 data in Section II of this paper. A spares package is developed to allow completion of a specified thirty-day sortie profiles with this spares package is noted. The ability to fly alternative sortie profiles with this spares package under various assumptions about logistic support, battle damage and attrition is then analyzed.

To demonstrate and evaluate this methodology, the rest of this section is devoted to analyzing the F-15 as if it were a system in the early stages of development. This involved using aggregated F-15 data to see whether a sufficient approximation of the results obtained from actual data could be achieved. If a reasonable approximation of results from actual data could be obtained, this would indicate that the method could be used for new systems.

We took the actual F-15C LRU data and aggregated it to a level similar to that which might be available for a new system. Using a method described in Reference 3, we divided the F-15C LRUs into an 8-by-8 matrix based on the distribution of cost and failure rates. The categories are shown in Table III-1.

Table III-1. Range of Values for Costs and Failure Rates in Simulated Data

Category	Range of Values	
1	0	to m/8
2	m/8	to m/4
3	m/4	to m/2
4	m/2	to m
5	m	to 2m
6	2m	to 3m
7	3m	to 6m
8		> 6m

For costs, m = mean cost, in dollars, of the total unique items. For failure Rates, m = mean number of failures per flying hour, weighted by quantity per aircraft (QPA) of the total unique items.

Thus, LRUs with low costs and low failure rates appeared in the top left of the matrix; LRUs with high costs and high failure rates appeared in the bottom right of the matrix. The LRUs we examined are distributed as shown in Table III-2. The distribution is skewed in the sense that many more LRUs fall into the low-cost, low-failure rate segment of the matrix (181 LRUs fall into the top left 3-by-3 segment) than into the high-cost, high-failure rate segment (13 items fall into the bottom right 3-by-3 segment).

To construct the simulated data set, we assigned the LRUs in each cell the midpoint of the cost and failure rates in each cell. However, for the 13 high-cost, high-failure rate items in the lower right corner, it is assumed that actual costs and failure rates are known. Details of the construction of the simulated data set are contained in Appendix D. Thus, a simulated data set for a new system could be generated with only these elements:

- Mean cost
- Mean failure rate

- A distribution of LRUs into cost and failure rate categories for a similar historical system.
- Specific costs and failure rates for items anticipated as high drivers (optional).

Table III-2. Matrix of F-15C LRUs, Categorized by Cost and Failure Rate

Failure rate per flying hour weighted by QPA

Cost (dollars)	0-0.00054	0.00054-0.00108	0.00108-0.00217	0.00217-0.00433	0.00433-0.00866	0.00866-0.01300	0.01300-0.02599	<0.02599
0-2258.93	41	24	29	19	15	6	7	3
2258.93-4517	18	15	14	15	6	2	2	1
4517.86-9035	10	15	15	5	5	1	5	0
9035.72-18071	6	7	11	7	6	0	2	0
18071.44-36142	1	7	6	9	7	3	1	0
36142.88-54214	1	3	1	4	2	1	0	2
54214.32-108428	0	3	1	1	4	1	1	3
> 108428.64	0	0	1	3	4	3	2	0
Total	77	74	78	63	49	17	20	9

Note: Numbers in cells are the total number of LRUs that fall within a particular cost-failure rate category.

Figure III-2 presents the results of the sparing runs for the actual data and the simulated data. As the figure indicates, costs are quite similar for the actual and simulated, data, within 37 percent for the normal-reliability case. At high reliability, the costs are within 57 percent, and at low reliability the costs are within 32 percent.

We also performed evaluation runs to see the sortie generation capability results derived from using simulated data. Figure III-3 presents the number of sorties achieved with simulated data under conditions of maintenance delay, attrition, and battle damage.

Comparison of Figure III-3 with Figure II-4 indicates that the numbers of sorties achieved were almost identical with the simulated data and the actual data. Spares costs per sortie, however, were quite different. For example, the cost results derived from using simulated data were 43 percent higher than the results of actual data in the normal-reliability case.

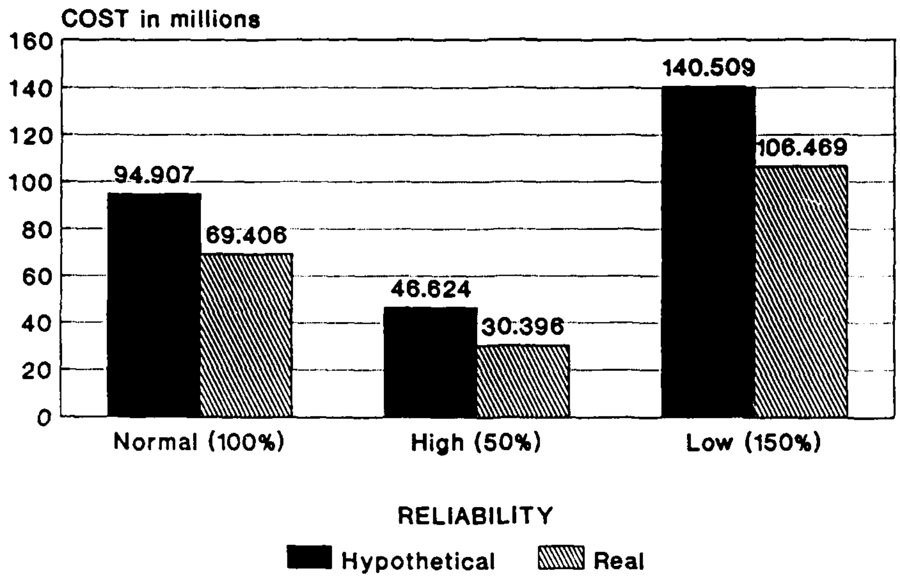


Figure III-2. Cost Comparison, Simulated Data with 13 Actual Items

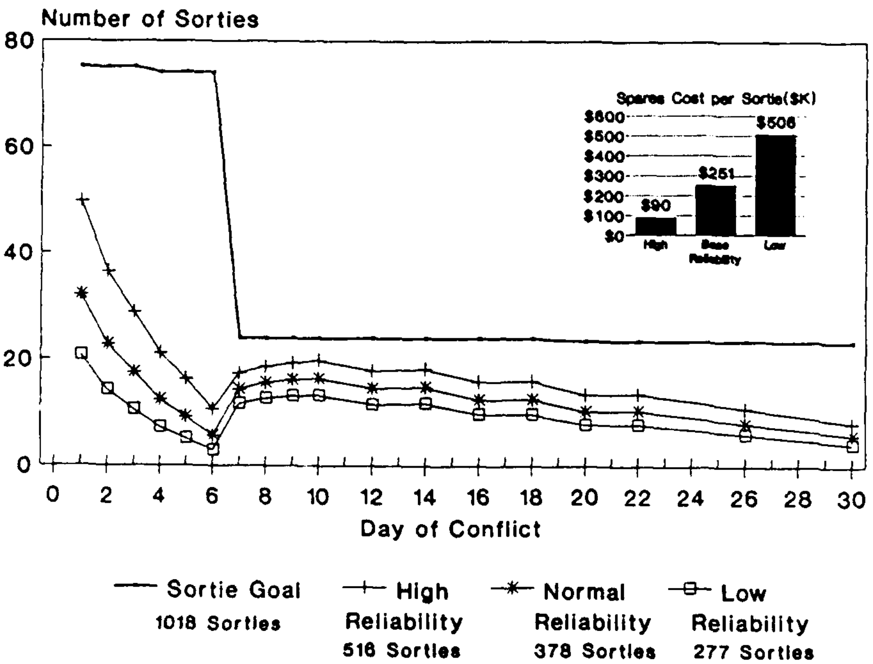


Figure III-3 Sorties Achieved with Hypothetical Data, Maintenance Delay, Attrition and Battle Damage (13 Actual Items)

C. FEATURES OF NEW AVIONICS SYSTEMS THAT SHOULD BE CONSIDERED

1. Introduction

The three Services are each developing next-generation aircraft that will bring together advanced avionics technologies and design concepts on a scale new to operational systems. The new avionics promise improved availability and lower support costs, but have not yet rigorously demonstrated these features in simulated scenarios or in actual flying experience. For these reasons, assessing the value of the new avionics with regard to sortie generation and spares costs is especially important.

Specific information on the Services' aircraft programs is generally unavailable, because the programs are classified or the aircraft have not yet entered full-scale development. Nonetheless, the design features that planners will exploit to achieve availability and support cost goals have been discussed in the open literature. Further, officials at the LHX and ATF program offices have discussed their general quantitative goals for these critical design features with us. Thus, a notional, advanced aircraft can be characterized in sufficient detail for the sake of our analysis.

The IDA methodology described in this paper must be extended to apply it to aircraft carrying the new avionics. For example, we did not rigorously address maintenance-related variables in our study of the F-15, yet key personnel in the ATF and the LHX aircraft programs agree that new maintainability features will play an important role in achieving aircraft availability and support cost improvement goals. In our study of the F-15, we varied the inherent reliability of the aircraft's components, but availability enhancements in next-generation aircraft involve new design features that promise benefits beyond the increased system reliability. Thus, IDA methodology must be modified to account for new maintainability and reliability enhancement features of next-generation aircraft. The remainder of this section characterizes these features and describes their predicted effects on availability and support costs.

2. Reliability

A significant increase in the inherent reliability of avionics equipment is expected to be the dominant reliability feature in next-generation avionics. For example, the F-16's APG-66 radar has an observed MTBF of approximately 200 hours, an order of magnitude greater than the F-4C Phantom II's radar and more than twice that observed for the F-

15A's radar. The mean time between critical failure (MTBCF) planned for an ATF's active aperture radar is an order of magnitude that exceeds the APG-66's radar.

While these major reliability increases may be achieved in some subsystems, they will probably not be the rule for every subsystem in the next-generation aircraft. Nevertheless, designers do seek a substantial increase in equipment reliability from the aircraft currently in the inventory.

The strategies for achieving large increases in reliability vary with the equipment under consideration, though generally they will include the following:

- Reducing environmental temperatures
- Making maintenance-induced failures less likely
- Substituting advanced connection schemes for conventional connectors, wires, and cables
- Using VHSIC (Very High Speed Integrated Circuits) microchips with a limited capacity for self-repair
- Replacing analog devices with digital devices.

While the expected level of inherent reliability is not an architectural feature of the new avionics systems, it may interact with other features in ways that make it important to represent them explicitly.

The design of next-generation aircraft will also include redundancy at the line-replaceable-module level as a means of reliability improvement. However, at this level, the concept of reliability is not focused on individual equipment but rather avionics functions, as embodied in the concept of <u>fault tolerance.</u>

Fault tolerance is the capacity of a system to provide a function (such as inertial navigation) <u>to some degree</u> despite the loss of equipment that normally provides the function (ignoring fault tolerance in the software domain). Three kinds of hardware redundancy strategies can be implemented to provide fault tolerance: <u>hardware repetition,</u> "<u>hot sparing</u>," and <u>reallocation of functions.</u>

Hardware repetition involves collectively providing an avionics function with a set of n identical devices that all operate during a mission. If function fails, the remaining n-1 are sufficiently capable of continuing to provide the avionics function. This redundancy strategy appears in the U.S. Air Force's Ultra-Reliable Radar, a variant of which may be used in the ATF. Hundreds of identical transmit-receive (T-R) modules collectively replace a single, conventional transmitter-receiver. As a result, the failure of a small number of T-R modules does not significantly degrade the radar's total performance under specified conditions. Another U.S. Air Force system that implements this redundancy strategy is the ALQ-184 electronic countermeasures pod. Multiple minitube transmitters collectively replace a single, conventional transmitter in the ALQ-184, so the loss of a small number of the minitube transmitters leaves the system relatively intact. Fly-by-wire flight control systems of such contemporary aircraft as the F-16 and the F/A-18 represent another variation of hardware repetition. All flight control systems function during normal operations, and the loss of any one of them does not affect the aircraft's overall performance.

Hot sparing, a second type of redundancy, involves backing up a device with one or more nonoperative spares. Hot spares do operate during a mission and accumulate flight hours toward their own failure; however, unlike hardware repetition redundancy, hot spares do not contribute to the aircraft's normal functioning. A hot spare functions only when it assumes the functions of a failed device.

A third type of redundancy, reallocation of function, involves shifting the functions of a failed device to some other device(s). These devices, differ from hot spares in that they are already providing other functions for the aircraft. This reallocation of function may degrade the aircraft's performance. This possibility of performance degradation depends on several factors regarding the substituting device, such as the number and concurrency of the demands the aircraft and pilot make on the substitute device, its inherent capacities, and what methods the device uses for handling simultaneous demands.

3. Maintainability

With regard to aircraft availability and sortie-generation capacity, maintainability complements reliability. High reliability keeps an aircraft flying, and high maintainability ensures that an aircraft is quickly returned to the flightline once a part has failed or is damaged. The maintainability features of next-generation aircraft important to availability and to maintenance requirements are based on three main design concepts: the line replaceable module (LRM), accurate fault detection, and accurate fault isolation. These features also enable other features, which are also discussed in the following paragraphs.

LRMs are SRU-like in physical and functional size. However, designers expect to substantially replace the larger LRUs with LRMs as the unit of flightline maintenance. If the LRMs can be given a sufficiently accurate capability for fault isolation, the avionics intermediate shop (AIS) and its attendant costs might be substantially eliminated.

Designers also hope to reduce the numbers of spares types required for an advanced aircraft, by satisfying a given avionics functional requirement with a single type of LRM as often as possible. For example, each of an aircraft's avionics functions (flight control, radar, communication, navigation) may have a requirement for a power supply. The design concept, *commonality*, would dictate using a single type of LRM to satisfy the common power supply requirement wherever possible. This design practice also seeks to standardize the use of LRMs across different aircraft for the same avionics requirements (power supply, bulk memory, data processing).

Planners believe that commonality will simplify aircraft maintenance by reducing the number of spares types and maintenance tools types required. Commonality and standardization are also expected to provide production cost advantages because of the economical production rates. Large quantity requirement for common and standard LRMs will also result in savings due to the standard learning curve benefits cited in cost analysis.

VHSIC-generation microelectronics will allow designers to install more extensive self-test facilities on next-generation aircraft than has been previously possible. However, with ubiquitous built-in test and diagnosis, the challenge facing planners of next-generation aircraft is the more difficult task of designing capabilities for accurate fault detection and fault isolation.

While the rate of correct fault detection can be increased by lowering a detection threshold, this method inevitably increases the number of false alarms reported. The challenge is to design systems that simultaneously attain satisfactorily high correct - detection rates and satisfactorily low false-alarm rates. Fault detection goals for next-generation aircraft are detection of 95 percent of all faults of interest, and 5 percent of all faults reported will be false alarms.

Once a fault has been reported, the cause of the report must be attributed to one or more failed units or isolated. The accuracy of fault isolation is measured in terms of the number of line replaceable devices in the ambiguity group, the set of line replaceable devices that includes a failed device. Because the fault cannot be isolated beyond the ambiguity group, all members of the ambiguity group must be removed, even though it may contain one or more functioning devices. Therefore, fault isolation accuracy directly affects spares requirements. In addition, because functioning devices may be damaged when they are removed (maintenance-induced faults), the size of the ambiguity group an indirectly influence spares requirements. Designers of next-generation aircraft hope to make the aircraft's built-in diagnostics capable of fault isolating to ambiguity groups of one at least 90 percent of the time and to ambiguity groups of no more than two the majority of the time.

By attaining a sufficient level of module-level fault isolation capability, planners believe that they can selectively eliminate the current LRU as the unit of flightline fault isolation and maintenance. Fault isolation to SRUs now may occur at AISs. Thus, fault isolation to SRU-size devices at the flightline will allow for selective elimination of the AIS. This will reduce the cost of acquiring and maintaining the AIS, and, reducing the size of the AIS will confers saving in terms of the cargo aircraft requirements and the time needed for squadron deployment.

In addition, replacing LRUs with LRMs as the unit of flightline maintenance may also produce cost savings on the maintenance system in terms of spares requirements. For example, even if fault isolation has identified a single LRU as the source of a fault detection report, replacing it removes a number of functioning SRUs as well as failed SRUs. Thus, substituting LRMs for LRUs as the unit of flightline maintenance will make the removal process more efficient if faults can be isolated to sufficiently small ambiguity groups with adequate frequency.

Designers are also anticipating several other benefits that are enabled by accurate fault isolation and the adoption of common LRMs The most significant benefit is probably a reduction in maintenance personnel requirements for a given level of aircraft availability. Current estimates of the size of reduction, while preliminary, range from 25 percent and 50 percent overall.

4. Summary

The preceding paragraphs outlined the significant design features of the new avionics systems that will appear in next-generation aircraft. The focus on maintainability and reliability issues as the means to improving availability and support costs requires us to extend the methodology used in studying the F-15. The method for doing this is described in the following section.

D. METHODS FOR EVALUATING THE EFFECT OF TECHNOLOGY IN THE NEXT-GENERATION TACTICAL FIGHTER ON SORTIE GENERATION AND SUPPORT COSTS

The development process for the new avionics represents an opportunity for a case example to demonstrate the evaluation of the value of reliability in a new system. Following a new system from its start of concept definition to initial operational capability (IOC) would be the ideal method for doing this. While a full-scale evaluation is beyond the scope of this effort, we have considered how such an evaluation might be implemented.

1. Simplest Analysis--System Level

The simplest analysis that might be considered involves excursions from our F-15 estimates. The goals for ATF system reliability are broadly consistent with the Air Force's Double R-Half M program--double reliability, halve maintenance. If these goals are achieved at the system level, and the distribution of reliability improvement is even across subsystems, then the sortie generation results of our high-reliability analyses represent a first approximation of the ATF. These results indicate that increased reliability has a major effect on the ability to fly sorties. This effect increases as the stress placed on the scenario (in terms of challenging sortie schedules, maintenance delays, battle damage, and attrition,) increases.

This simple analysis, however, has some serious limitations. First, it assumes no change in underlying technology. The costs of LRUs are assumed to remain the same the increased reliability has been achieved without additional cost. This is conceivable; some believe that concurrent engineering can result in enhanced quality at the same or even lower cost (see Reference 4). However, more reliable components may result in greater cost.

In addition, costs for manpower and support equipment may also change, a possibility not considered in this simple analysis. Finally, the F-15C data base used in our analysis does not consider most of the engine and some of the airframe components, because these parts are separately supported or are not considered mission essential.

Another limitation of this analysis is that it assumes that the increased reliability is achieved across-the-board, not by varying the reliability of individual components, which may be a more efficient way to achieve it.

Nevertheless, this simple analysis indicates that increased reliability results in enhanced aircraft availability.

2. More Detailed Analysis--The simulated data methodology

The simulated data method requires relatively few data. This methodology requires knowledge of only the number of modules, the average cost of a module, and the average failure rate of a module.

If these data are available, a simulated data set can be developed at the LRU level, using a distribution from a similar system. (This method was demonstrated in Section III.2.) This data set can than be used in the Dyna-METRIC model to develop estimates of spares costs and sortie generation capability under combat conditions, using Air Force sparing methods.

The more detail available, the better the results achieved from this method. In particular, if approximate values are known for the highest cost and highest failure rate items, the method yields a closer approximation of spares costs.

3. More Complete Analysis

A more complete analysis of the ATF would result in several benefits. More specific data on costs and failure rates of LRMs could be incorporated in the design process as they become available. How architectural features (accurate fault isolation, fault tolerance, and reduced number of connectors) enhance the increased inherent reliability in the ATF could be considered. We believe that redundancy can be analyzed using the features of Dyna-METRIC. Proper modeling of reallocation of function would require a considerable effort. However, from conversations with personnel in the ATF program, we concluded that reallocation of function will occur mainly when an aircraft has sustained significant battle damage and has lost some of its avionics function. Reallocation of function thus affects sortie-generation capability and maintenance requirements mainly through aircraft survivability and so can be represented as part of the attrition rate.

A more complete analysis of the ATF would also enable consideration of maintenance policy for fault-tolerant features. Maintenance efforts have traditionally focused on fixing failures. However, in a fault-tolerant system, an LRM can fail and the system can remain fully mission capable. Based our discussions with those knowledgeable about the ATF, there seems to have been much discussion about the maintenance policy for such a system but few decisions. In peacetime, it is likely that all failures will be repaired as soon as possible. Maintenance policy for wartime is less clearly defined. The best solution from a modeling standpoint appears to be to model at least two cases, one in which all failures are repaired immediately, and the other in which failures are repaired only when the aircraft cannot fly a sortie unless the repair is made. A third case, opportunistic maintenance, would assume that noncritical repairs would be performed if they did not interfere with the sortie program.

A more complete analysis of the ATF would also include consideration of the operating plan for the ATF, including higher sortie goals and operation and maintenance from diverse locations;.consideration of improved time to repair as a result of easier access to LRMs and faster fault isolation; and consideration of costs of manpower and support equipment.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Our objectives in this analysis were to assess the value of reliability in a wartime context and to begin to develop a method for assessing the reliability of prospective systems.

This analysis has shown that increasing system reliability results in increased sortie generation capability in wartime conditions. When maintenance delay is included in the analysis, higher reliability results in a 14 percent higher sortie rate, with a 62 percent reduction in spares cost per sortie. Another issue we wanted to explore is how stressful combat conditions affected the value of reliability. The usual planning factors often do not allow for some conditions that are very likely to occur. For example, battle damage places demands on the maintenance system and creates delays and downtime. It was unclear whether reliability might be unimportant when time must be taken to repair battle damage; our analysis indicated that, even with a relatively high level of battle damage, reliability has substantial value. In the most severe combat condition case--one that includes maintenance delay, attrition, and battle damage, higher reliability results in a 33 percent increase in the number of sorties achieved, with a 67 percent reduction in cost per sortie.

Challenging sortie schedules also underscore the value of reliability. When spares are purchased for a normal sortie schedule and then a more challenging flight schedule is attempted, which may occur if a conflict becomes intense, reliability results in substantially more sorties. In the most severe case we examined--a 30-day surge situation with maintenance delay, attrition, and battle damage--the high-reliability fighter achieved 358 sorties, and the normal-reliability fighter achieved only 233.

The second major objective was to begin to develop a method for assessing the value of reliability in prospective systems. Our goal was to determine how this assessment can be made without a firm configuration or hard data on costs and failure rates. The IDA method allows for an initial assessment using with only the most general information. As the information expands and improves, the method accommodates it.

New system architectures present challenges for modeling. When reliability improvements can be made without major architecture change, the value of reliability can be assessed relatively easily. However, the advanced modular avionics architecture achieves greater system reliability through innovative designs in addition to increased inherent reliability of individual components. Improved fault detection and fault isolation, redundancy, reallocation of function, and reduced numbers of connectors are planned for the avionics systems, to be used on the ATF, the A-12, and the LHX, among others. Our conclusion is that the IDA models and methods can be adapted to assess the reliability of the most important features of these advanced architectures.

We have developed a framework for the analysis of reliability in new systems. This analysis can indicate the benefits of additional reliability, but it does not reflect all the costs or all the cost savings of additional reliability. Examining the cost dimension in more detail is essential, because cost must be balanced against the corresponding benefits.

B. RECOMMENDATIONS

Combat conditions--maintenance delay, battle damage, and attrition--substantially affect a squadron's ability to fly sorties. We believe that the Services should more closely consider combat conditions when determining which parts are mission essential and in building spares kits. The goal should at least be to spare as you would expect to fight. Perhaps it should be to spare as you fear you may have to fight.

The services should consider instituting more reliability improvement programs for tactical aircraft. Spares cost savings aside, reliability has substantial payoff in combat.

The new avionics architectures must be evaluated using appropriate techniques. While these new architectures offer potential for significant support cost savings, they also present considerable difficulties in analysis, due to some special features not previously used or used less extensively. However, if these new architectures are not sufficiently analyzed, their potential benefits may not be adequately recognized during the acquisition process.

Additional research to refine and validate the method of assessing new systems should be performed. Analyses of additional systems are needed to examine whether different distributions should be used to develop simulated data for different kinds of systems.

In addition, the cost and cost savings from enhancing quality are vital questions that require further study. All phases of the acquisition process should be addressed. Cost estimating relationships that include reliability as well as physical and performance characteristics should be developed.

REFERENCES

[1] Dubek, 1st Lt. Robert D., *Insights to Aircraft Battle Damage Repair through Combat Data,* AFWAL-TM-85-228-FIEA, Flight Dynamics Laboratory, AF Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio, July 1984.

[2] Issacson, K; Boren, P., Tsai; C:. and Pyles R., *Dyna-METRIC Version 4: Modelng Worldwide Logistics Support of Aircraft Components,* Report No. R-3389-AF, The Rand Corporation, May 1985.

[3] Ince, John F.; Evanovich, Peter; *Timely Analysis of the Readiness of New Systems.* Report No. CRM 86-119, Center for Naval Analyses, June 1986.

[4] Winner, Robert I.; Pennell, James R.; Bertrand, Harold E.; and Slusarczak, Mark M.G.; *The Role of Concurrent Engineering in Weapons System Acquisition* IDA Report R-338, Institute for Defense Analyses, December 1988.

[5] Alexander, Arthur J. *The Cost & Benefits of Reliability in Military Equipment,* The Rand Corporation, Paper P-7515, December 1988.

APPENDIX A

THE DYNA-METRIC MODEL--CAPABILITIES, OUTPUTS, AND LIMITATIONS

This appendix describes the Dyna-METRIC model's capabilities which include assessing systems performance in a dynamic wartime scenario and assisting in identifying factors that may limit operational performance. Some of the model limitations are also discussed. (The reader seeking additional detail is referred to References A-1 to A-3.)

Dyna-METRIC was selected as the primary model to use in studying the effect of aircraft repairable spares on warfighting capability. The model provides a representation for predicting fully mission capable (FMC) status of a complete squadron of Air Force aircraft. The model accepts a flying hour program for scenarios up to several months in length. Output from the model includes expected sortie generation capability along with a listing of potential problem parts for RRR (Remove, Replace and Repair) and RR (Remove and Replace) maintenance items.

One major reason for selecting the Dyna-METRIC model for use in the IDA study is that Dyna-METRIC is used by the Air Force to determine the components and repair parts to stock in WRSKs (War Reserve Spares Kits) and BLSS (Base Level Self-Sufficiency Spares) to support up to 30 days of austere wartime flying. In addition, the Dyna-METRIC model is currently one of the leading models for generating reliability insights for items such as electronic warfare equipment.

The Air Force Logistics Command (AFLC) is using Dyna-METRIC in its Weapon System Management Information System (WSMIS) to assess theater-level supportability of wartime operating plans. WSMIS is being expanded to assess repairable spares and engines for almost all AF weapon systems. Dyna-METRIC spares assessments are closely related to the requirements process used to compute AF authorizations.

Dyna-METRIC computes an expected pipeline value, which becomes the minimum quantity for each part. A safety level is then added using a marginal analysis procedure until a specified NMCS (Not Mission Capable Status) and backorder goal is achieved for the squadron.

WRSK/BLSS computations assume that the failure rates for most parts are functions of flying hours. For non-optimized (NOP) items such as guns, landing gear, and support equipments, the required quantities for the kits are manually determined based upon expert judgment supported by whatever demand data are available.

Air Force Logistics Assessment Exercises such as Coronet Warrior have indicated a close relationship between Dyna-METRIC model results and actual exercise experiences. (See Appendix B.)

A. CAPABILITIES OF DYNA-METRIC

Dyna-METRIC provides a detailed representation of the logistics system for many individual aircraft components--particularly in the areas of component demand processes such as time, flying hour, and onshore and offshore demand factors, and repair processes such as Not Repairable This Site (NRTS) indicators. Different repair times at different echelons may be considered by the model, along with different repair resources and scope of repair at different echelons. The model can also do depot workload and stockage computations and can compute base-level stockage with a no-cannibalization constraint. (Cannibalization is the practice of transferring a serviceable component from one aircraft to another.) Cannibalization is used only when a serviceable component needed to repair one aircraft cannot be obtained from local supplies and another aircraft is already unserviceable because of failure of other components.

The primary measure of performance for the model is the calculation of the FMC aircraft and sorties generated from the flight-line. The Dyna-METRIC model can simulate one or more types of aircraft, at one or more bases located in one or more theaters of operations, for a period of time that may range from several days to several years. The model can predict the effect of the logistics support system on the bases' ability to execute their assigned flying programs.

Aircrafts can operate out of a base on a fly-out, fly-back sortie program (as fighter aircraft typically do) or on a fly-in, fly-out program (for example, a cargo aircraft flying a circuit). In either case, broken parts arrive with incoming planes but, in the case of cargo aircraft, removals of failed components may be more likely at some bases than at others.

Although aircraft of a given type are usually assumed to be identical, they can be flown on different missions at different times. For example, a base might fly air-to-air missions for some initial period and subsequently fly ground attack missions. The flying programs to be executed may vary over time. The number of aircraft can increase with the deployment of new units and decrease due to attrition or the reassignment of aircraft. The number and length of sorties may vary each day, as can the maximum single aircraft sortie rate, which limits the number of sorties that can be flown by one operational aircraft in a single day. With this flexibility, the model can accommodate almost any conceivable flying program, including the peacetime or wartime scenarios.

1. Aircraft

Aircrafts are assumed to have an indentured component structure: an aircraft is composed of LRUs (Line Replaceable Units) that are composed of SRUs (Shop Replaceable Units) that are composed in turn of sub SRUs. (Sub SRUs would include both bits and pieces that are consumed during repair of the SRU and other repairable components that may be repaired either locally or at a higher echelon.)

Dyna-METRIC views the entire aircraft as a collection of LRUs, SRUs and sub SRUs. Certain major aircraft components, such as the engines, are generally not indicated LRU numbers, but they can be treated as LRUs by the model.

In the model, aircraft availability is a direct function of the availability of the aircraft's LRUs. SRUs affect aircraft availability only through their ability to support the repair of their parent LRUs, and sub SRUs affect aircraft availability through their support of the repair of SRUs.

A given LRU may be on an aircraft one or more times. LRUs can be classified as essential, wholly or partially redundant. If wholly or partially redundant, more than one unit must fail before the aircraft is rendered Not Fully Mission Capable (NFMC).

LRUs may also be classified as essential or non-essential to a particular mission that the aircraft can execute. For example, a plane with a broken radar unit might be incapable of executing an air-to-air mission but capable of ground attack.

The model also accommodates the possibility of limited differences in the components on the aircraft location at a single base. This situation may occur when components are being phased in or out or when some of the aircraft are specially equipped.

2. Logistics System

In the Dyna-METRIC model, repairable components essentially move upward in a hierarchical level of repair stations. Repairable parts are removed from aircrafts at the flightline, and are serviced at the base level. If not repairable there, they are transported to a Centralized Intermediate Repair Facility (CIRF) and serviced. If not repaired at the CIRF, they are sent on to the depot. Parts at any level can be condemned as not repairable. Stocks of serviceable spare parts may be held at each level, and over time these serviceable spares are sent down the hierarchy to replace the repairable ones that have been sent up.

The repair capabilities of each level can be modeled in considerable detail. Repair for LRUs can be specified as unconstrained or constrained. In the unconstrained case, maintenance is assumed to begin as soon as a component arrives at a repair facility. In the constrained case, the arriving components join a queue of other components also awaiting service. Components are selected from this queue based on a priority scheme that minimizes maximum back orders rather than on a first-come, first-served basis. How long a component waits for service depends on how many aircraft are NFMC relative to other components and on how heavily loaded the repair facility is In addition to handling repairable items, Dyna-METRIC can handle consumables if these components are assigned a condemnation rate of 100 percent.

Dyna-METRIC portrays the component support processes as a network of pipelines through which components flow as they are repaired or replaced. Each pipeline segment is characterized by a delay time that arriving components must spend in the pipeline before exiting the segment. Some delay times, such as local repair times, vary from component to component; others, such as intratheater transportation times, depend on the base being assessed. There may also be times when components are frozen in their pipeline segments and do not flow. For example, the transportation segments are modeled as being frozen when a transportation cutoff is in effect.

Failed components enter the pipeline network at the bases' flightlines. Each base has a flightline support capability that removes and replaces those components, drawing serviceable spares from local supply as needed to repair aircraft. Each base may also have component repair shops that test the failed components and return them to serviceable condition. For units deploying to new bases, the repair capability may be available only after some delay, while the repair facility is being deployed and set up.

Once components have been removed from an aircraft they are repaired at a local shop or sent to other facilities for repair. If the component can be repaired locally it is returned to local stock. If the component cannot be repaired at all, the base condemns the component and requisitions a replacement.

If the component cannot be repaired at the base, it is declared NRTS and sent to either a CIRF or a depot, and a replacement component is requisitioned. Replacement components are requisitioned from the facility to which the NRTSed component is sent; that facility will immediately send the base a serviceable spare if one is available. If none is available, one will be sent as soon as possible after all prior requisitions for the same component have been filled. Once the repairable component reaches the CIRF or the depot it is repaired and returned to that facility's stock so that it can be issued to satisfy the next demand.

If a component is sent to a CIRF and the CIRF cannot perform the repair, the CIRF will either condemn the component or send it to the depot, and will requisition a replacement component from the depot. If a component is sent to the depot and the depot cannot perform the repair, the depot condemns the component and orders a replacement from the supplier. (If the scenario does not permit resupply of the depot, the supplier may be cut off.) As LRUs are processed at the various facilities, failed SRUs may be discovered. The SRU repair and resupply network is essentially the same as that for LRUs, as is the repair and resupply network for sub SRUs.

3. How the Model Represents the Logistics System

The key equation in Dyna-METRIC computes the expected pipeline contents for each LRU, SRU, or sub SRU. The expected number of each component is calculated for each segment of the pipeline network. The computation is based on the planned time-dependent aircraft flying activity or (optionally) on the achievable PMC and FMC time-dependent aircraft flying activity.

The model computes the removals caused by the flight plan activity, and then, using the time-dependent availability and delays associated with transportation and repair at bases, CIRFs, and depots, and the likelihood that the component will be classified as NRTS or condemned, determines the expected contents of each pipeline segment. The segments are totaled to forecast the total pipeline size which is the expected quantity on order and in local repairs as seen by each base. The expected total pipeline size is the key parameter for a probability distribution that describes the number of components in the network, as seen at each base's flightline. That is, the expected total pipeline size is used to determine the probability that there are two components, the probability that there are three components, and so on.

Dyna-METRIC combines each component's dynamic demand and repair process time to estimate the expected pipeline quantity for each pipeline segment. The dynamic demands for pipeline segments after the base repair pipeline segment are derived from the dynamic departures from the preceding pipeline segment. For example, the LRUs entering the base-to-CIRF pipeline are just the NRTS rate times the departures from the base repair pipeline segment.

The model computes expected pipeline quantities for each LRU's, SRU's, and sub SRU's repair pipeline segments at base, CIRF, and depot and transportation segments between these locations. SRUs awaiting parts at each location are computed for the number of sub SRUs in stock and under repair, and LRUs awaiting parts are computed from SRUs in stock, in repair, and awaiting parts.

Backorders at depots and CIRFs are computed from quantities in stock, quantities in repair, quantities of awaiting parts, and on-order. Those backorders are allocated to bases under a first-come, first-served rule. The expected base pipeline for LRUs, SRUs, and sub SRUs then consists of items in local repair and on order from higher echelons (i.e., in transit and backorder.

B. OUTPUTS OF THE MODEL

Given a description of a scenario, the profile of the aircraft, and the logistics system, Dyna-METRIC provides various measures of performance. Besides traditional component-oriented logistics statistics such as backorders, Dyna-METRIC provides higher combat capability-oriented measures related to the force's ability to generate sorties. The combat measures include aircraft availability and daily sortie generation capability. For each operating location the model reports the expected number of available aircraft at any specified time and at any specified confidence level. For example, Dyna-METRIC might report that on day five of a scenario a given base could expect, on average, 16 available aircraft, but that only 13 aircraft will be available with 95 percent confidence.

Dyna-METRIC also estimates the expected number of sorties a base can generate on any specified day. The model assumes that a base never overflies the program specified in the scenario (though the base may fail to achieve its program due to a shortage of available aircraft), so the predicted sortie generation capability will be less than or equal to the scenario's flying program. Thus, the model's daily sortie estimates reflect both requested sorties and available aircraft.

Higher-order performance measures are quite sensitive to whether or not LRUs can be cannibalized from one aircraft to repair another. Aircraft availability and sortie generation are typically much higher under a full cannibalization policy than under one of no cannibalization. The model allows the user to label each LRU as cannibalizable or not cannibalizable, and then computes aircraft availability and sortie generation first using this data, then assuming a policy of full cannibalization. A policy that permits no cannibalization can be modeled by marking all components not cannibalizable.

From the expected base pipeline value, the model derives the probability that a given number of components are in repair or on order at each base. Using these total pipeline probability distributions for each component and the component's available stock at each base, the model next forecasts how the LRUs in repair and on order would (probabilistically) generate backorders (or aircraft "holes") for each component at a given time. It then distributes those holes across aircraft for two alternative cannibalization policies. For full cannibalization, Dyna-METRIC assumes that all component holes at each base are instantly consolidated on the fewest possible aircraft, thus making as many FMC aircraft as possible.

For partial cannibalization, holes of LRUs flagged as not cannibalizable are assumed to occur randomly across the aircraft at each base. Holes of cannibalizable LRUs are then consolidated onto the aircraft that are already down for noncannibalizable LRUs. Leftover holes are consolidated onto as few of the remaining aircraft as possible. In each case the model derives a full probability distribution for the number of degraded aircraft from which the fields in the capability assessment report are directly obtained. In particular, the expected number of NFMC aircraft and the expected number of FMC sorties are computed and reported for both cannibalization policies.

Dyna-METRIC generates a report that identifies the LRUs that are most likely to be a problem for at least one base, and sorts them by the number of aircraft they are likely to ground. This report is especially helpful when the projected performance is unsatisfactory. For these LRUs, the model reports:

- How many aircraft they will probably ground
- How many aircraft they would ground if the base level spares were most effectively redistributed
- Where in the logistics system the LRUs are tied up (such as, queued for repair at the CIRF, in transit from the depot, awaiting serviceable SRUs at a base.)

- Which SRUs (and sub SRUs) are tied up and where, if they limit LRU availability.

Two requirement computations are incorporated in the model. The stockage algorithm optionally computes stock with simple, single component fill rate goals or with full- or no-cannibalization FMC aircraft goals. The depot workload requirement computes the maximum and minimum workload necessary for a depot surge to meet its expected requisition levels for each component.

The pipeline probability distributions are used to compute stockage requirements. For this option, Dyna-METRIC recommends additional LRU, SRU and sub SRU stock to achieve an NFMC goal at the lowest cost. Two general strategies are employed: buying spares to ensure that each component will individually achieve a target NFMC limit (disregarding other components) and buying spares so that all LRUs jointly achieve the NFMC limit. Note that the first strategy does not achieve the goal of the second. Suppose that there are two LRUs, and each has a .1 probability of causing too many NFMC aircraft, so there is sufficient stock of each under the first strategy. But the probability that at least one of the two components will cause many NFMC aircraft is .19, so additional stock must be purchased to achieve the more ultimate aircraft-oriented goal under the second strategy.

If the user's objective is only to ensure that each LRU does not violate the NFMC limit with the stated confidence level, the model uses the LRU's individual pipeline probability distributions and increases each LRU's stock level until the stated confidence level is achieved for that component alone. If the objective is to ensure that all of the LRUs jointly achieve either a certain confidence of fewer than the stated percent NFMC, with full cannibalization, or expected NFMC less than a target NFMC percent with no cannibalization, the model first makes sure that each LRU achieves the goal individually, it "buys" more LRUs across the full range of LRUs to achieve the overall goal. In either case the model employs a marginal analysis technique. It first determines how much closer to the goal the user would be with an additional unit of LRU 1, LRU 2, or LRU 3, and so on. It then it adds an additional unit of the LRU with the best benefit to cost ratio and it continues to add LRUs in this manner until the goal is attained.

A final Dyna-METRIC option is computing the maximum possible wartime depot repair workload (the expected daily arrivals for depot repair), the minimum required wartime depot workload (the minimum number of LRUs that must be inducted on each day into depot repair to satisfy expected depot requisitions), and the amount of LRU stock needed at the depot to offset repair and retrograde transportation delays under dynamic wartime conditions.

C. LIMITATIONS

Dyna-METRIC has several limitations that arise from the model's mathematical assumptions, approximations, and program implementation constraints. Generally, the mathematical assumptions exist because of the current state of the art in the modeling of inventory systems. Overcoming these limitations will require new mathematical breakthroughs. Using mathemetical approximations reflects design choices that trade off mathematical rigor against extra computer time.

Dyna-METRIC's eight most frequently noted limitations are tied to mathematical assumptions, approximation, or implementation constraints:

- **Unconstrained repair may overestimate or underestimate performance.** In the model's simplest uses where constrained repair is not modeled, the mathematics underlying the model make two key assumptions about demands, transportation, and repair processes. First, demands arrive randomly according to one of two well-known arrival probability distributions (Poisson or negative binominal), and second, repair and transportation times have known probability distributions that are independent of the demand history. Neither of these assumptions is likely to be exactly true. Thus, these two assumptions may cause the model either to underestimate or overestimate the logistics system performance if repair resources are not explicitly modeled. If one can judge that the demand and repair processes do not deviate radically from these assumptions, the model should be relatively accurate.
- **Lateral resupply is not modeled explicitly.** The assumption that demands, repair, and resupply functions are independent also prevents the model from directly assessing the effects of lateral supply across bases. Essentially, lateral supply would have the same effect as expedited resupply from a higher echelon. Because the effective resupply time would depend on the history of prior demands, repairs, and resupplied items, lateral resupply violates the model's underlying mathematical assumptions. An approximate workaround exists for this situation, however. If CIRFs are not being used for any other purpose in an analysis, one can model several related bases as being supported by a CIRF. Some of the theater's stock can then be relocated to the CIRF to be requisitioned and shared across all the bases to simulate lateral resupply.
- **The model assumes that aircraft deployed at each base are nearly identical.** It does allow for some fraction of the base's aircraft to have additional LRUs, but it assumes that aircraft can be described as subsets of other aircraft. The assumption is critical to the computation of both the full cannibalization and the partial cannibalization of FMC aircraft. Again, a workaround exists if the CIRF feature is not being used in the analysis. One can represent each real base with multiple aircraft types as several bases with a common CIRF containing the base's stocks for all the aircraft. By setting the

base-to-CIRF and CIRF-to-base transportation times to zero, one can assess how both unique and common components' support affects the capabilities of multiple aircraft types.

- **The constrained repair computations are only approximate.** The model uses a deterministic, expected value computation to compute the expected pipelines for constrained, priority repair, so it only approximates real world repair processes. Further, it applies the resulting component pipeline distributions as though they were independent. Thus, the constrained repair computations only approximate likely logistics system performance, particularly when using the model to assess peacetime queueing. Scenario idiosyncrasies may cause some components' backorders to grow until they nearly match the worst component. Then, the model would not consider the correlations induced by priority repair, and it would provide an overly pessimistic assessment of performance. In such a case, one can use the model's problem LRUs report to detect an overly pessimistic assessment. If two or more LRUs that share a repair resource rank near each other in their NFMC impact, the assessment may be somewhat pessimistic.

- **Ordering policies for economic order quanities (EOQ) and consumables are not modeled.** Some spare parts are so small or inexpensive that they are ordered in economic order quantities greater than one at a time (to avoid the trouble and cost of excess paperwork and handling). The model's mathematics apply precisely only to those cases where the order quantity is one. The mathematics are only approximately accurate for larger order quantity policies. As the order quantity increases, the pipeline variability would also effectively increase. One can work around this approximately by increasing the demand variance-to-mean ratio proportional to the square root of the order quantity. The pipeline variability will then reflect the expected variability due to the order quantity.

- **Expected backorders and awaiting parts quantities approximate additive pipelines.** For computational efficiency, the model does not compute the joint probabilistic effects of backorders and awaiting parts quantities with related pipelines. Instead, the expected values of these quantities are added to the appropriate pipelines as though they were also Poisson or negative binomial distributions. This is not strictly correct. To treat this rigorously, the model must convolve the related probability distributions--a task that would greatly increase computer time. However, tests of the approximation show that only modest errors are introduced in the computations of total base component breakdowns or NFMC aircraft when the expected back orders or awaiting parts quantities are small (less then 1). When these quantities increase, the errors appear to decrease.

- **Flightline and operational constraints are not explicitly modeled.** Operational constraints and flightline resources affect the sortie rates that can be achieved with an FMC aircraft. These factors are beyond the scope of the Dyna-METRIC model, so they do not appear explicitly. Nevertheless, their effects can be estimated in other models or analyses and incorporated in the Dyna-METRIC model sortie rate parameter.

- **Computers have limitations such as word size representation that may affect the model's precision and accuracy.** Unlike the mathematics upon which it is based, the computerized model cannot always carry out its computations with infinite precision. Computer and programming language manuals generally provide maximum and minimum quantities that can be represented. A program like Dyna-METRIC computes extremely small probabilities and adds them up in various ways. Often, a computed probability will be smaller than the programming technique used can represent. Summing these small numbers, or almost zeroes, leads to cumulative errors called numeric instabilities, which may affect the model's results. Dyna-METRIC partially compensates for this effect when possible by using logarithms, which permit the model to represent much smaller numbers. In general, Dyna-METRIC encounters numerical instabilities only in rare cases when the expected pipeline sizes grow extremely large, beyond several thousand units (depending on the computer). Such an instability will result in an extraordinary value for the number of NFMC aircraft--nearly all aircraft will be NFMC. When one encounters such a situation, the problem LRUs report will indicate that one or more LRUs (or SRUs) have very large pipelines. Removing the offending component from the analysis will usually correct the problem. Such components are usually analyzed more appropriately outside the rigorous confines of a model like Dyna-METRIC.

Most of these limitations do not affect the current analysis. Despite any known limitations, Dyna-METRIC is a useful model for the type of analysis IDA is performing. The model allows analysis of a variety of operating tempos and logistic support scenarios at a reasonable level of detail and reasonable computer cost.

REFERENCES

A-1. R.J. Hillstead. *Dyna-METRIC: Dynamic Multi-Echelon Technique for Recoverable Item Control.* Rand R-2785-AF, July 1982.

A-2. R. Pyles. *The Dyna-METRIC Readiness Assessment Model, Motivation, Capabilities, and Use. Rand R-2886-AF, July 1984.*

A-3. K.E. Issacson, C. Tsai, P. Boren, R. Pyles. *Dyna-METRIC Version 4: Modelling Worldwide Logistics Support to Aircraft Components.* Rand WD-2659-AF, June 1985.

APPENDIX B

MODEL VALIDATION--THE CORONET WARRIOR EXERCISE

One of the most difficult tasks in research analysis is trying to determine whether the model is valid. While much has been written about the model validation problem, no truly satisfactory solutions have been proposed, and many writers take refuge in philosophical abstraction or statistical mathematics. The following sections describe a more common sense approach to a validation process for Dyna-METRIC.

A. GUIDELINES FOR MODEL ASSESSMENT

Model validity is often confused with truth and attempts that are made to prove that something is true. Model assessment is quite different: it is the process by which we establish sufficient confidence in the Dyna-METRIC model to use it for the intended purpose.

The only absolute test of a model's validity that is theoretically possible is to observe and record events from an actual system in an actual environment at a suitable time. However, in general this type of testing is very difficult to do in practice; true validation of a model that simulates wartime activity is nearly impossible. For this reason, validation should be used as a confidence-boosting exercise. Because models are built for a distinct purpose, model assessment should be used to determine whether the model meets an intended purpose. Models cannot be classified as absolutely valid or completely invalid, except in relation to a particular purpose, and a model that serves for one purpose may be misleading if used for another.

The following questions are suggested guidelines for model assessment:

- Are the functional system boundaries properly considered in terms of intended use by the model? If the model does not include the parts of the system that can be changed to influence operational behavior, it is virtually useless and therefore invalid. For example, a model might present an excellent treatment of air-to-air munitions effectiveness after launch, but ignore potential problems in transporting the aircraft with the munitions to the combat area.

- Do any gross model errors exist? For example a model which produces, negative results when positive results are obviously appropriate is not particularly useful because its results are conceptually impossible or are beyond all system logic Errors of this type may be due to simple mistakes. Alternatively, they may arise from failure to model constraints properly or to represent decision functions realistically or from dimensional errors. Model validation is not simply a statistical exercise in curve fitting but primarily a matter of judgment, even when statistical procedures are employed.
- Does the model structure sufficiently correspond with the system being studied? The analysts must be confident in using the model and managers must be confident in making decisions based on insights gained from using the model. The model should accurately represent the system. A check must be made to ensure that the proper variables have been correctly interconnected and the decision functions in the model reasonably reflect those actually used, which is very difficult to do. Data are rarely available to verify that the modeled decision function reflects what was done in the past. Even when these data are available, they can only be used to reject an obviously incorrect formulation. In practice, a sound approach is to conduct a simulation session with managers or decision-makers. They should be asked what they would do under various sets of circumstances; the model should then be made to function similarly for the same reasons.
- Are the dimensioning values correct? (This is, in many ways, a minor question.) The dynamics of a system are usually not greatly affected by many of these, providing they are within a fairly broad range. However, some of the dimensions will be more critical, and changing the limits on the values may change the behavior mode observed in modeling the system.
- Does the model reproduce the system behavior? To answer this question, time series of important values from the system could be compared to series for the same variable from the model. The model would be considered "INVALID" if its values do not sufficiently agree with the historical values from the system. This classical approach is often allied to very sophisticated statistical procedures but some very serious difficulties may occur in application.

In practice, total model validation is rarely possible, as the data are usually not available. Even when data can be found, they relate only to the measurable system states and rarely to the policies by which these states are controlled. Comparing model output to actual data can be frustrating unless one also knows that the policies were stable and were consistently applied. Rejecting a model because one or two of its outputs do not match an uncertain past data history is not necessary.

Unfortunately, most of the statistical tests for the agreement between two time series (the model's and the actual data) require about 30 data points. Even with monthly data it is unlikely that one could find a representative two-and-one-half year period during which few system changes occurred and from which actual measurable data is available. For a quarterly model, finding or collecting the required amount of data is virtually impossible.

Generally, the best method for building confidence in a model is ensuring that the model has been carefully designed in conjunction with management.

B. AIR FORCE LOGISTICS ASSESSMENT EXERCISE CORONET WARRIOR

The Dyna-METRIC model used in the IDA study has been validated through Air Force logistics assessment exercises, such as Coronet Warrior, which have indicated a close relationship between Dyna-METRIC model results and actual exercise experiences.[1]

The Coronet Warrior exercise was specifically designed to evaluate Dyna-METRIC's ability to predict Fully Mission Capable (FMC) aircraft, sorties, and potential problem parts in a Remove, Repair, Replace (RRR) maintenance scenario. The purpose of the exercise was to evaluate the logic and implementations of the standard Air Force spares methodology, particularly the ability of Dyna-METRIC to predict unit capability.

For the exercise, the 94th Tactical Fighter Squadron at Langley Air Force Base isolated its F-15C squadron at home station with only the aircraft, personnel, and equipment that would be deployed in a wartime contingency. No resupply was allowed, and the unit used its actual on-hand War Reserve Spares Kit (WRSK) assets with one exception--the on-hand quantities of a handful of items were reduced to a level that supported a Dyna-METRIC prediction of a C-2 sortie flying level, as defined by the Air Force Logistics Command. This represented a 71 percent fill of WRSK assets. The unit operated for 30 consecutive days working 12-hour shifts.

Data were collected on nearly all aspects of the exercise to support a wide range of follow-on analysis. Of primary concern was the comparison of predicted and actual performance and the reasons for any deviations, with the intent of correcting any model, data, or unit procedural deficiencies identified.

---

1 Information presented at LOGCAS-88, a USAF-sponsored Logistics Capability Assessment Symposium, April 1988, US Air Force Acedemy, Colorado Springs, Colorado.

Dyna-METRIC predicted that the unit would fly only 91 percent of its tasked sorties (C-2 level), losing sorties toward the end of the surge period and the end of the exercise. The unit would be capable of flying only 15 sorties on the last day. The unit actually flew 98 percent of the tasked sorties, losing a few sorties on various days throughout the exercise.

The differences between actual and predicted performance were more dramatic with respect to the FMC aircraft. A fully authorized WRSK is supposed to support 18 of 24 aircraft on day 30. With the 71 percent filled WRSK, Dyna-METRIC predicted the unit would only have 4 FMC aircraft at the end of 30 days. However, the WRSK was adjusted to provide a C-2 sortie level, which was even achievable with the low predicted number of FMC aircraft because each aircraft can fly an average of 3.5 sorties per day.

The unit actually had 17 FMC aircraft left and flew 98 percent of tasked sorties versus the 91 percent predicted. The actual FMC aircraft levels should have been sufficient to support 100 percent of tasked sorties, but the 2 percent of sorties lost were due to factors not considered by the model. An analysis of the model and current data sources revealed sound model logic (except for some types of repair), but with some key data problems.

Predicted and actual performance differed for several reasons. The main reason was that the ten predicted major problem parts did not fail at the anticipated rate. All of these items were non-optimized or electronic warfare components whose demand rates are difficult to predict. Many parts failed less often than predicted, but a few failed at much higher rates than expected and would have jeopardized the outcome of the exercise if intermediate-level maintenance were not available for these items. A small portion of the differences between predicted and the actual results was caused by the repair logic of the model, which did not account for priority repair actions and assumes few constraints on test equipment and personnel.

The repair area of the model does need some improvements. In general, the high-failure-rate parts were repaired faster and more successfully than the model predicted. The repair logic in Dyna-METRIC does not adequately represent limited availability of test equipment nor priority repair actions.

From the Coronet Warrior exercise, many valuable lessons were learned about Dyna-METRIC, WRSK configuration and makeup, consumable equipment reliability, the value of repair capability, and maintenance management at a wartime tempo. Much of this information can be applied to improve logistics supportability planning for new weapons systems such as the ATF.

C. OTHER VALIDATION EXERCISES

Other validation exercises include F-4s at Leading Edge I and F-16s at Leading Edge II. These exercises indicated that Dyna-METRIC reasonably predicts general levels of sortie capability and identifys key problem items. However, both of the Leading Edge tests were limited in scope (lasting only 6 to 7 days with no repair capability), which somewhat limited the evaluation.

In the Leading Edge exercises, the evaluation of Dyna-METRIC was conducted on a non-interference basis and was not a significant portion of the exercise. In contrast, the primary purpose of Coronet Warrior was to evaluate the Dyna-METRIC model; therefore, data collection and unit procedures were established to assist in the evaluation.

D. CONCLUSIONS

Dyna-METRIC modeling techniques, when used with reasoned inputs, produces appropriate WRSK requirements. The repair logic in the model needs some improvement in the area of equipment constraints and priority repair.

Variability of demand for parts is a reality that complicates any forecasting attempts. The value of intermediate maintenance to compensate for such variability has been clearly demonstrated.

The exercise method of assessing a model identifies the problems associated with data availability. No single best source of data can be identified. Despite the dramatic improvement in modeling assessment, many areas require improved methods for measuring the effect of logistics resource shortfalls on aircraft sortie generation capability.

APPENDIX C

PROCEDURES USED IN DEVELOPING DYNA-METRIC OUTPUTS

A. INTRODUCTION

The purpose of this appendix is to discuss how Dyna-METRIC outputs are developed. It includes an overview of Dyna-METRIC elements; input specifications; execution of Dyna-METRIC, including procedures for sparing and evaluation runs on the Institute for Defense Analyses (IDA) VAX 8600 machine; generation of statistical tables using VAX tools such as SAS, FORTRAN, and INGRES, and PC software such as DBase and EXCEL; and generation of graphics on the VAX using GRAPHIC OUTLOOK, and on the PC utilizing Harvard Graphics. New VAX and PC versions of the model currently being implemented at IDA are also discussed.

B. OBJECTIVES

The objective of this appendix is to describe, in detail, how to execute the Dyna-METRIC model on the VAX 8600 and generate graphics from the outputs of the model on the VAX 8600 and PC.

C. OVERVIEW OF DYNA-METRIC DATA ELEMENTS

The Dyna-METRIC model was developed by RAND to assess worldwide logistics support for aircraft components. Dyna-METRIC will model one or more types of aircraft at one or more bases located in one or more theaters of operations for a period of time determined by input. The model predicts the effect of the logistics support system on the bases' ability to execute their assigned flying programs.

The Dyna-METRIC model provides information on the following items:

- Inventory requirements to meet specified levels of supply readiness
- Readiness and sortie generation capability of aircraft in terms of logistics support and operational considerations,

- Effects of repair capacity and priority repair.

Input data requirements of the model include the following:

- Force levels or number of aircraft
- Flying hour program that includes the peacetime rate
- Number of sorties per day for each day of the wartime portion of the scenario
- Flight hours per sortie
- Complete list of Line Replaceable Units (LRUs) on the aircraft
- Removal rate for each LRU
- Quantity per aircraft for each LRU
- Level of repair for each LRU
- Not Repairable This Site (NRTS) rate for each LRU
- Turn Around Time (TAT) for each LRU
- Resupply time for each LRU
- Battle damage rate
- Mean time to repair for each LRU
- Attrition rates of aircraft (if any).

D. OUTLINE OF INPUT SPECIFICATIONS

1. General Notes

- All fields must be non-negative unless otherwise specified.
- A blank is considered to be the same as a zero.
- Each record group can only appear once in an input data set.
- Times are specified in days, but any consistent unit is acceptable for Dyna - METRIC.
- Peacetime values, represented by day 0, are assumed to have been in effect forever. Wartime begins on day 1 and lasts throughout the length of the scenario.

2. Operation and Support Scenario Data

The following are required input data:

ACFT: Aircraft Level Specification

This record specifies how many aircraft are assigned to each base during peacetime and on each day of war. Bases for which ACFT records are not given will be assigned no aircraft. The following example specifies 24 aircraft for days 1 through 30 for base BS01.

```
ACFT
BS01    0.0      1 24. 999
```

BASE: Base Description Record

This record describes the availability of repair and resupply at each base, the name of the Centralized Intermediate Repair Facility (CIRF) (if any), and describes the transportation resources connecting the base and CIRF. A record is required for each base. The following example specifies that for base BS01, the base to CIRF transportation time is 1 day, the CIRF to base transportation time is 1 day, the resupply CIRF start day is 0, the CIRF availability does not continue to empty prior to the day set in the previous field, the CIRF cut-off day is 1, the CIRF cut-off duration is 30 days, the resupply start day is 30, the resupply cut-off day is 1, the resupply cut-off duration is 30 days, the Remove and Repair (RR) repair start day is 33, the remove, repair, and replace (RRR) repair start day is 5, the sustained demand start time or the day that components begin to break according to the demand rate is 31.01, and the repairable arrival time is 0.00.

```
BASE
BS0    11.00  1.00  0.000  1.0030.0030.000  1.0  30.0  33.0  5.0  31.01  0.0000.00  10
```

OPT: Option Selection Record

This record defines the options that generate Dyna-METRIC's reports. The following example asks Dyna-METRIC to purchase stockage at 15 percent aircraft degradation with an 80 percent confidence level and to evaluate the performance based on input and currently purchased stocks.

```
OPT
          3  15          .80
          4  15          .80
         12  15          .80
```

SRTS: Sortie Rate Specification

This record specifies the average :.ımber of daily sorties required per aircraft at each base during peacetime and on each day of war. Aircraft at bases for which SRTS records are not given will fly no sorties. The following example specifies for base BS01

3.13, sorties are required for days 1 through 3, 3.09 sorties are required for days 4 through 6, 1.00 sortie is required for days 7 through 19, 0.98 sortie is required for days 20 through 29, and 0.97 sortie is required for day 30.

```
SRTS
BS01 0.0     13.13    43.09    71.00   200.98   300.97 999
```

TURN: Maximum Sortie Rate Specification

This record specifies, at each base, the maximum number of sorties a mission-capable aircraft can fly per day during peacetime and on each day of war. Aircraft at bases for which TURN records are not given will fly no sorties. The following example specifies that for base BS01, the maximum sortie rate of 4.5 for days 1 through 30.

```
TURN
BS01 4.5    1 4.5    4 4.5    7 4.5   20 4.5 30 4.5 999
```

The following are optional input:

ATTR: Attrition Rate Specification

This record specifies the fraction of aircraft that are attrited per sortie at each base on each day of the war. Aircraft at bases for which ATTR. records are not given do not experience any attrition. The following example specifies for base BS01 an attrition rate of 0.02 for days 1 through 6, and an attrition rate of 0.01 for days 7 through 30.

```
ATTR
BS01    0.0    1 .02    4 .02    7 .01    20 .01    30 .01 999
```

CIRF: CIRF Description Records

This record describes the availability of repair and resupply at each CIRF.

DEPT: Depot Description Records

This record describes the availability of repair and resupply at each depot.

FLHR: Flying Hours Per Sortie Specification

This record specifies how many flying hours are required per sortie at each base during peacetime and each day of the war. Aircraft at bases for which FLHR records are not given will be assumed to fly sorties of one hour each. The following example specifies flying hours of 2 for days 1 through 30 for base BS01.

```
FLHR
BS01 0.0    1  2.    4  2.    7  2.  20  2.  30  2. 999
```

ILM: Maintenance Deployment and Setup Specification

This record names the different types of maintenance that apply to the LRUs and specifies the time each becomes available at each location. The following example specifies that for base BS01, the remove and repair (RR) types are available on day 33, the remove, repair, and replace (RRR) types are available on day 5, and O-level maintenance (OLMT) types are available on day 1.

```
ILM
      RR    RRR   OLMT
BS01  33.0  5.0   1.0
```

MESL: Mission Requirements Specification

This record specifies which missions the aircraft at each base fly during peacetime and on each day of war. Aircraft at bases for which MESL records are not specified are assumed to fly all missions.

TRNS: Depot Transportation Record

This record describes transportation resources connecting bases and CIRFs with depots. If a record is not entered for some base-depot or CIRF depot pair, transportation between the two is assumed to be instantaneous and never cut off.

3. Component Description Data

The following are required input:

LRU: Line Replaceable Units Description Records

This record describes the failure, repair, and resupply characteristics of each LRU. The following example specifies that for LRU item 1005000566753, one item per aircraft exists, an onshore and offshore demand rate of 0.00060, a lone base repair time of 5.2 days, a lone base condemnation rate of 0.03, a CIRF-served base repair time of 4.0 days, a CIRF repair time of 4.0 days, a depot repair time of 4.0 days, a peacetime resupply time of 16 days, a wartime resupply time of 30 days, and a cost of $29,940.00.

```
LRU
1005000566753         1 0   1  1   .00060 .00060   5.2 0.03          4.0 0.00
1005000566753    x 4.0 0.00        4.0                016. 030. 00029940.
```

The following are optional input:

APPL: Application Fractional Data

This record specifies the fraction of each base's aircraft that contains a given LRU. Bases for which application fractions are not specified default to application fractions of one. The following example specifies that for LRU item 1005000566753 at base BS01 an application fraction of 1.00 exists.

```
APPL
1005000566753     BS01  1.00
```

INDT: Indenture Specification

This record specifies which SRUs are indentured to which LRUs and which sub SRUs are indentured to which SRUs.

QPA: Quantity per Aircraft Data

This record specifies the quantity per aircraft of each component for each base. Bases for which QPA records are not entered use the quantity per aircraft data specified in the LRU, SRU, and Sub SRU record groups.

SRU: Shop Replaceable Units Description Records

This record describes the failure, repair, and resupply characteristics of each SRU.

SSRU: Sub SRU Description Records

This record describes the failure, repair, and resupply characteristics of each sub SRU.

STK: Stockage Level Specifications

This record specifies each component's level of stock at the depots, CIRFs, and bases. The following example specifies for LRU item 1005000566753, at base BS01, a stock level of 0.

```
STK
1005000566753     BS01     0
```

TEST: Constrained Repair Availability Records

This record describes the availability of different types of constrained repair, such as test equipment, skilled personnel, and equipment disassembly fixtures.

TBED: Server Level Records

This record specifies how many servers per constrained repair resource are available at each location during peacetime and on each day of war. Locations for which TBED records are not entered are assigned no servers.

TPRT: LRUs Tested Specification

This record specifies which LRUs are assigned to the constrained repair resource named in the immediately preceding TEST record group.

VTM: Variance to Mean Data

This record specifies an LRU's maintenance type and gives its wartime demand rate multipliers, LRU pipeline variance-to-mean ratio, and the probability that a partially mission capable repair resource will be able to repair the LRU. The following example specifies for LRU item 1005000566753, an RRR type with an onshore demand rate multiplier of 1.00, an offshore demand rate multiplier of 1.00, a variance to mean ratio of 1.00, and a partial repairability of 0.00.

```
VTM
1005000566753      1 1.00 1.00 1.00 0.00 11111
```

4. Ordering of Input Record Groups

Line 1 and 2: Comment cards

Line 3: Days of evaluation
- OPT data group
- DEPT and CIRF data group (if any)
- BASE data group
  - all other optional scenario records
  - ACFT data group precedes ATTR data group
- LRU data group
  - all other optional component records
  - TEST data group precedes TBED and TPRT data groups
  - VTM data group precedes SRU and SSRU data groups
- INDT, QPA, and STK data groups follow

For additional information on data description and data input specification of parameters, see Reference C-1.

5. Sample Input Data File

```
         XXXXXXXXX DR:100 RRRSTART:5 MD:NO BD:NOAT:NO TRANS¹
         1 0.00 0.00          VERSION 4.4  MT1MT2MT3MT4MT5
         1   5   10  15  20  25  30
2a3:     OPT
               3 14  .80
               4 15  .80
               8 50  .80
               9
               12 15  .80
2a2:     BASE
         BS01   1.00 1.00 0.000 1.0030.0030.000 1.0 30.0 33.0 5.0 31.01
2a1:     ACFT
         BS01  0.   1 24. 999
2a4:     SRTS
         BS01 0 0    13.13    43.09    71.00   200.98   300.97 999
2b4:     FLHR
         BS01 0.0    1  2.   4  2.   7  2.  20  2. 30  2. 999
2b1:     ATTR
         BS01  0.0   1  .00  4  .00  7  .00  20  .00  30  .00 999
2a5:     TURN
         BS01 4.5    1 4.5    4 4.5    7 4.5   20 4.5 30 4.5 999
3a1:     LRU
         1005000566753          1 0 01 01    .00060 .00060  5.2 0.03        4.0 0.00
         1005000566753    X 4.0 0.00         4.0               016. 030. 00029940.
         1270010405948          1 0 01 01    .00820 .00820  9.1 0.08        7.0 0.00
         1270010405948    X 7.0 0.00         7.0               014. 030. 00050369.
         1270010469884          1 0 01 01    .00680 .00680  9.1 0.11        7.0 0.00
         1270010469884    X 7.0 0.00         7.0               014. 030. 00064321.
         1270010635567          1 0 01 01    .00730 .00730  7.8 0.10        6.0 0.00
         1270010635567    X 6.0 0.00         6.0               014. 030. 00124585
               .
               .
               .
               .
               .
               .
               .
         6680011288000PT        1 0 02 02    .00730 .00730  6.5 0.88        5.0 0.00
         6680011288000PT X 5.0 0.00          5.0               014. 030. 00010712.
         6685003336763          1 0 01 01    .00050 .00050 10.4 0.93        8.0 0.00
         6685003336763    X 8.0 0.00         8.0               016. 030. 00000415.
         6685010482889NT        1 0 02 02    .00140 .00140  9.1 0.73        7.0 0.00
         6685010482889NT X 7.0 0.00          7.0               014. 030. 00002984.
         7021004775716          1 0 01 01    .00070 .00070  7.8 0.74        6.0 0.00
         7021004775716    X 6.0 0.00         6.0               014. 030. 00049372.
3b7:     TEST data group (if any)
3b8:     TBED data group (if any)
3b9:     TPRT data group (if any)
3b1:     APPL
         1005000566753       BS01  1.00
```

---

[1] Xs denote spaces for comment, DR denotes demand rate (100,150,or 50), RRRSTART denotes RRR starting day, MD denotes maintenance delay (yes/no), BD denotes battle damage (yes/no), AT denotes attrition (yes/no), TRANS denotes transportation starting day.

```
        1005001886968       BS01  1.00
        1005001886969       BS01  1.00
        1005002790528       BS01  1.00
            .
            .
            .
            .
            .
            .
            .
        6680011288000PT     BS01  1.00
        6685003336763        BS01  1.00
        6685010482889NT     BS01  1.00
        7021004775716        BS01  1.00
3b10:   VTM
        1005000566753       1  1.00  1.00  1.00  0.00  11111
        1270010405948       1  1.00  1.00  1.00  0.00  11111
        1270010469884       1  1.00  1.00  1.00  0.00  11111
        1270010635567       1  1.00  1.00  1.00  0.00  11111
            .
            .
            .
            .
            .
            .
            .
        6680011288000PT     0  1.00  1.00  1.00  0.00  11111
        6685003336763         0  1.00  1.00  1.00  0.00  11111
        6685010482889NT     0  1.00  1.00  1.00  0.00  11111
        7021004775716         0  1.00  1.00  1.00  0.00  11111
3b4:    SRU data group (if any)
3b5:    SSRU data group (if any)
3b2:    INDT data group (if any)
3b3:    QPA data group (if any)
3b6:    STK data group (if any)
        END
```

E. EXECUTION OF DYNA-METRIC FROM THE VAX

1. Summary of Programs

- **SEXXXXX.COM** is a command procedure program that executes the source programs and concatenates all the Dyna-METRIC output files into a single file, -COMBO.DAT.
- **MODIFYLRU2.FOR** is a **FORTRAN** program that changes the demand rate of a given data set and generates maintenance delay or new parts for the LRU.
- **LRU-VTM-CARDS.WRK** is a **GRAPHICS OUTLOOK** file that calculates the battle damage cards for the LRU and VTM sections of the data file.

2. Dyna-METRIC Source Programs

The following source programs must be accessible through a directory:

V44PARTS.EXE
V44ECHOS.EXE
V44PIPES.EXE
V44MODS.EXE
V44REPORTS.EXE
PARAM.PARAM.

3. Required Files AND PROGRAMS

The following files must be present at the working directory:

A complete dynametric data file
SEXXXXX.COM.

4. General Execution Procedures of Dyna-METRIC

a. Edit and Rename SEXXXXX.COM

In EDT, substitute XXXXX the file name of the data set. The <s> or substitute command in EDT replaces a string with another specified at the line where the cursor is located. By denoting the <w> or whole option, the substitute command replaces the string throughout the file. The file name of the data file should not exceed eight characters. The directory must be set where the source programs are located for the run/nodebug statements.

```
>edit SEXXXXX.COM
*s/xxxxx/filename/w
*exit filename.com
```

EDT must be exited using the same file name as the data file so the data file that is being executed could be tracked. This will also allow SEXXXXX.COM to be a working shell program.

b. Submit .COM file

The submit command in VAX executes the command procedure program in B.

```
>submit file name.COM/queue=fast or queue=moderate
```

Note that the moderate queue allows more CPU time for execution.

c. Check .LOG file

Execution of the .COM program generates a .LOG file that contains the errors, if any, during execution. When execution of the model is successful, the .LOG file will contain five FORTRAN STOPS.

d. Output

The following files are generated by the model:

PIPE

MOD

REPORT

ECHO

PART

The copy command in the .COM program copies all of the output files that are of interest into another file *filename*- COMBO.DAT. Since all of the output from the model is contained in -COMBO.DAT file, all of the output files can be deleted from the directory to recover some computer space.

```
>delete file name*_pipe_*.dat.*,file name*_mod_*.dat.*,
file name*_report_*.dat.*,filename*_echo_*.dat.*,
filename*_part_*.dat.*
```

This statement can be included in the .COM file after the **COPY** statement.

5. Procedures for Producing Sparing Runs

Sparing runs are runs in which Dyna-METRIC purchases stocks to be used in the evaluation runs. Sparing runs are made with the OPT card at 3 and 4. In some cases, error 241 is observed. (Errors are contained in the .LOG file.) This error can be overcome by executing options 3 and 4 separately. If error 241 does not occur when options 3 and 4 are executed together, the following procedures, used to produce the stock list, can be omitted.

Execute **.COM** file with option 4 taken out in the data set. A list of stocks bought will be generated. This file is contained in file

***filename* _RPT_3_STOCK2_OPT9_EQ_1.DAT.**

Attach the stock list generated under the STK card in the data set. This is done in EDT: place the cursor under the STK card in the data set, and issue EDT command INCLUDE *filename*_RPT_3_STOCK2_OPT9_EQ_1.DAT. Delete option 3 and execute .COM file with option 4. Another stock list will be produced. The stock list produced by the option 4 based on the stock list generated by option 3 will be used in execution of evaluation runs.

The following is a sample data file used in sparing runs.

```
BUY-3&4-AFLC  DR:100  RRRSTART:5  MD:0HR  BD:NO  AT:NO  TRANS:31
1 0.00 0.00         VERSION 4.4   MT1MT2MT3MT4MT5
  1   5  10  15  20  25  30
OPT
   3 14  .80
   4 15  .80
   8 50  .80
   9
  12 15  .80
  26      27
BASE
BS01        1.00  1.00  0.000  1.0030.0030.000   1.0  30.0  33.0   5.0  31.01  0.0000.00
ACFT
BS01     0.    1 24. 999
SRTS
BS01     0.0    13.13    43.09    71.00   200.98   300.97 999
FLHR
BS01     0.0   1  2.    4  2.    7  2.   20   2. 30   2. 999
ATTR
BS01     0.0   1  .00    4  .00    7  .00   20  .00   30  .00 999
TURN
BS01     4.5   1 4.5    4 4.5    7 4.5   20 4.5 30 4.5 999
LRU
1005000566753          1 0 01 01   .00060 .00060  5.2 0.03       4.0 0.00
1005000566753       X 4.0 0.00     4.0            016. 030. 00029940.
1270010405948          1 0 01 01   .00820 .00820  9.1 0.08       7.0 0.00
1270010405948       X 7.0 0.00     7.0            014. 030. 00050369.
1270010469884          1 0 01 01   .00680 .00680  9.1 0.11       7.0 0.00
1270010469884       X 7.0 0.00     7.0            014. 030. 00064321.
1270010635567          1 0 01 01   .00730 .00730  7.8 0.10       6.0 0.00
1270010635567       X 6.0 0.00     6.0            014. 030. 00124585.
1270011838987          1 0 01 01   .01050 .01050  9.1 0.16       7.0 0.00
1270011838987       X 7.0 0.00     7.0            014. 030. 00077474.
1280010423952          1 0 01 01   .01120 .01120  9.1 0.09       7.0 0.00
1280010423952       X 7.0 0.00     7.0            014. 030. 00037610.
1560010037178FX        1 0 01 01   .00110 .00110  7.8 0.22       6.0 0.00
1560010037178FX X 6.0 0.00        6.0            025. 030. 00078621.
1650003337185          1 0 02 02   .00140 .00140 10.4 0.36       8.0 0.00
1650003337185       X 8.0 0.00     8.0            011. 030. 00003340.
1650010503491          1 0 01 01   .00070 .00070 10.4 0.78       8.0 0.00
1650010503491       X 8.0 0.00     8.0            014. 030. 00042364.
1650010653500FS        1 0 02 02   .00080 .00080  7.8 0.79       6.0 0.00
1650010653500FS     X 6.0 0.00     6.0            014. 030. 00003654.
      .
      .
      .
      .
      .
      .
```

```
APPL
1005000566753      BS01  1.00
1005001886968      BS01  1.00
1005001886969      BS01  1.00
1005002790528      BS01  1.00
1005010429740      BS01  1.00
           •
           •
           •
           •
           •
           •
           •
VTM
1005000566753      1  1.00  1.00  1.00  0.00  11111
1270010405948      1  1.00  1.00  1.00  0.00  11111
1270010469884      1  1.00  1.00  1.00  0.00  11111
1270010635567      1  1.00  1.00  1.00  0.00  11111
1270011838987      1  1.00  1.00  1.00  0.00  11111
           •
           •
           •
           •
           •
           •
           •
STK
END
```

6. Procedures for Producing Evaluation Runs

Evaluation runs are runs in which Dyna-METRIC evaluates the performance and flying program of the aircraft based on the stocks purchased in the sparing runs. The following procedures are used:

- Attach stock list under STK card.

- Change days of evaluation (line 3 of the data set) to:

  1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 26 30

- Execute .COM file with data file set at options 11 and 18. Options 3 and 4 are taken out.

The following is a sample data file used in evaluation runs.

```
EVALUATION-AFLC  DR:100  RRRSTART:5  MD:0HR  BD:NO  AT:NO  TRANS:31
  1  0.00  0.00         VERSION  4.4   MT1MT2MT3MT4MT5
  1   2   3   4   5   6   7   8   9  10  12  14  16  18  20  22  26  30
OPT
```

```
    11 15  .80
    18
    26
    27
BASE
BS01        1.00  1.00  0.000  1.0030.0030.000   1.0  30.0  33.0   5.0  31.01  0.0000.00

ACFT
BS01  0.    1 24. 999
SRTS
BS01  0.0    13.13    43.09    71.00   200.98   300.97  999
FLHR
BS01  0.0   1  2.   4  2.   7  2.  20  2. 30  2. 999
ATTR
BS01  0.0   1  .00   4  .00   7  .00  20  .00  30  .00 999
TURN
BS01  4.5   1 4.5   4 4.5   7 4.5  20 4.5 30 4.5 999
LRU
1005000566753            1 0 01 01   .00060 .00060  5.2 0.03        4.0 0.00
1005000566753      X 4.0 0.00        4.0             016. 030. 00029940.
1270010405948            1 0 01 01   .00820 .00820  9.1 0.08        7.0 0.00
1270010405948      X 7.0 0.00        7.0             014. 030. 00050369.
1270010469884            1 0 01 01   .00680 .00680  9.1 0.11        7.0 0.00
1270010469884      X 7.0 0.00        7.0             014. 030. 00064321.
1270010635567            1 0 01 01   .00730 .00730  7.8 0.10        6.0 0.00
1270010635567      X 6.0 0.00        6.0             014. 030. 00124585.
1270011838987            1 0 01 01   .01050 .01050  9.1 0.16        7.0 0.00
1270011838987      X 7.0 0.00        7.0             014. 030. 00077474.
1280010423952            1 0 01 01   .01120 .01120  9.1 0.09        7.0 0.00
1280010423952      X 7.0 0.00        7.0             014. 030. 00037610.
1560010037178FX         1 0 01 01   .00110 .00110  7.8 0.22        6.0 0.00
1560010037178FX X 6.0 0.00        6.0             025. 030. 00078621.
1650003337185            1 0 02 02   .00140 .00140 10.4 0.36        8.0 0.00
1650003337185      X 8.0 0.00        8.0             011. 030. 00003340.
1650010503491            1 0 01 01   .00070 .00070 10.4 0.78        8.0 0.00
1650010503491      X 8.0 0.00        8.0             014. 030. 00042364.
1650010653500FS         1 0 02 02   .00080 .00080  7.8 0.79        6.0 0.00
1650010653500FS    X 6.0 0.00        6.0             014. 030. 00003654.
    .
    .
    .
    .
    .
APPL
1005000566753      BS01  1.00
1005001886968      BS01  1.00
1005001886969      BS01  1.00
1005002790528      BS01  1.00
1005010429740      BS01  1.00
    .
    .
    .
    .
    .
VTM
1005000566753      1  1.00  1.00  1.00  0.00  11111
```

```
1270010405948     1  1.00  1.00  1.00  0.00  11111
1270010469884     1  1.00  1.00  1.00  0.00  11111
1270010635567     1  1.00  1.00  1.00  0.00  11111
1270011838987     1  1.00  1.00  1.00  0.00  11111
     .
     .
     .
     .
     .
STK
END
```

7. Procedures for Producing Evaluation Runs With Maintenance Delay

New parts for the LRUs make up the Dyna-METRIC data file with maintenance delay. The new parts will have LRU numbers similar to the existing LRUs with different repair time and cost. The following procedures are used:

- Execute MODIFYLRU2.EXE

The FORTRAN program MODIFYLRU2.FOR generates new parts for the existing LRUs that will make up maintenance delay.

```
>run  MODIFYLRU2.EXE

Menu  of  MODIFYLRU:

1)  GENERATE  NEWPARTS  FOR  LRU  AND  VTM
2)  CHANGE  DEMAND  RATES  FOR  LRU
3)  MOVE  LRU  AND  VTM  NEWPARTS  TO  END
4]  QUIT

choose  option  1

ENTER  DESIRED  INPUT  FILE
DO  NOT  INCLUDE  THE  <.DAT>  PART  OF  THE  FILE  NAME.
>data file name

ENTER  A  NAME  FOR  THE  OUTPUT  FILE
THE  FILE  NAME  MAY  BE  UP  TO  10  CHARACTERS  LONG.
DO  NOT  INCLUDE  THE  <.DAT>  PART  OF  THE  FILE  NAME.
>filename

INPUT  THE  REPAIR  TIME
>0.083
```

- Execute .COM file with the new data file created above.

The following is a sample file that contains maintenance delay cards. The LRU items that end in N denote new parts.

```
EVALUATION -AFLC NEW MODEL DR:100 RRRSTART:5 MD:2HR BD:NO AT:NO TRANS:31
  1 0.00 0.00        VERSION 4.4  MT1MT2MT3MT4MT5
   1   2   3   4   5   6   7   8   9  10  12  14  16  18  20  22  26  30
OPT
      11 15  .80
      18
BASE
BS01       1.00  1.00  0.000  1.0030.0030.000   1.0  30.0  33.0   5.0  31.01  0.0000.00   10
ILM
      RR  RRR OLMT
BS01  33.0   5.0   1.0
ACFT
BS01   0.   1 24. 999
SRTS
BS01  0.0    13.13    43.09    71.00   200.98   300.97 999
FLHR
BS01  0.0   1  2.   4  2.   7  2.  20  2. 30  2. 999
ATTR
BS01   0.0   1  .00   4  .00   7  .00  20  .00  30  .00 999
TURN
BS01  4.5   1 4.5   4 4.5   7 4.5  20 4.5 30 4.5 999
LRU
1005000566753          1 0  1  1   .00060 .00060  5.2 0.03       4.0 0.00
1005000566753     X 4.0 0.00        4.0              016. 030. 00029940.
1005000566753N         1     1  1 1            .00060 .083 .00000000 0000
1005000566753N   X 4.0 0.00        4.0             .083  .083  999999.       1
1270010405948          1 0  1  1   .00820 .00820  9.1 0.08       7.0 0.00
1270010405948     X 7.0 0.00        7.0              014. 030. 00050369.
1270010405948N         1     1  1 1            .00820 .083 .00000000 0000
1270010405948N   X 7.0 0.00        7.0             .083  .083  999999.       1
1270010469884          1 0  1  1   .00680 .00680  9.1 0.11       7.0 0.00
1270010469884     X 7.0 0.00        7.0              014. 030. 00064321.
1270010469884N         1     1  1 1            .00680 .083 .00000000 0000
1270010469884N   X 7.0 0.00        7.0             .083  .083  999999.       1
1270010635567          1 0  1  1   .00730 .00730  7.8 0.10       6.0 0.00
1270010635567     X 6.0 0.00        6.0              014. 030. 00124585.
1270010635567N         1     1  1 1            .00730 .083 .00000000 0000
1270010635567N   X 6.0 0.00        6.0             .083  .083  999999.       1
     .
     .
     .
     .
     .
APPL
1005000566753     BS01  1.00
1270010405948     BS01  1.00
1270010469884     BS01  1.00
1270010635567     BS01  1.00
     .
     .
     .
     .
     .
VTM
1005000566753      1  1.00  1.00  1.00  0.00  11111
```

```
1005000566753N   2  1.00  1.00  1.00  0.00  11111
1270010405948     1  1.00  1.00  1.00  0.00  11111
1270010405948N   2  1.00  1.00  1.00  0.00  11111
1270010469884     1  1.00  1.00  1.00  0.00  11111
1270010469884N   2  1.00  1.00  1.00  0.00  11111
1270010635567     1  1.00  1.00  1.00  0.00  11111
1270010635567N   2  1.00  1.00  1.00  0.00  11111
      •
      •
      •
      •
      •
STK
1005000566753     BS01     0
1270010405948     BS01     9
1270010469884     BS01     7
1270010635567     BS01     7
      •
      •
      •
      •
      •
END
```

8. Procedures for Producing Evaluation Runs with Battle Damage

Calculation for battle damage cards is contained in the Graphics Outlook file LRU-VTM-CARDS.WRK. This file contains the battle damage data for the LRU and VTM cards. The following steps are used:

• Write LRU and VTM data portion of the spreadsheet LRU-VTM-CARDS.WRK to a file

```
>grlook  LRU-VTM-CARDS.WRK
~/pr
choose  WORKSHEET
from  menu:
    Worksheet  range  to  print:  R99:AF130
    Print  to  Printer:  NO
    Print  to  File:   YES
    Filename:   filename.out
```

• Include the output file fron the spreadsheet in the data set in EDT, place cursor under LRU card, and issue EDT command:

***include *filename*.out**

The .OUT file contains battle damage cards for both the LRU and VTM. The VTM portion must be placed under the VTM card of the data set. Cut the VTM battle damage portion in the data provided by the include command. Paste the cut VTM battle damage portion under the VTM card of the data set. The paste command in EDT recalls the EDT buffer that stores the latest cut. The paste is activated by pressing <PF1> followed by <6> on the number pad

The following is a sample data file with battle damage cards.

```
EVAL/BATDMG-AFLC NEW MODEL-DR:100 RRRSTART:5 MD:2HR BD:YES AT:
YES (15) TRANS:31
  1 0.00 0.00        VERSION 4.4  MT1MT2MT3MT4MT5
   1   2   3   4   5   6   7   8   9  10  12  14  16  18  20  22  26  30
OPT
11 15  .80
18
BASE
BS01          1.00  1.00  0.000  1.0030.0030.000   1.0  30.0  33.0   5.0  31.01  0.0000.00
ILM
      RR   RRR  OLMT
BS01  33.0   5.0   1.0
ACFT
BS01    0.    1 24. 999
SRTS
BS01  0.0     13.13    43.09    71.00   200.98   300.97  999
FLHR
BS01  0.0    1  2.    4  2.    7  2.   20  2.  30   2.  999
ATTR
BS01  0.0    1  .02   4  .02   6  .01   20  .01   30  .01  999
TURN
BS01 4.5    1 4.5    4 4.5    7 4.5   20 4.5  30 4.5  999
LRU
Structure              1    1  110  0.0930  0.09300.619    0.0   0.0
Structure                                                                  1
Flight Center          1    1  110  0.0154  0.0154  1.21   0.0   0.0
Flight Center                                                              1
Propulsion             1    1  110  0.0194  0.0194  3.65   0.0   0.0
Propulsion                                                                 1
Fuel                   1    1  110  0.0231  0.02310.208    0.0   0.0
Fuel                                                                       1
Power                  1    1  110  0.0178  0.0178  14.3   0.0   0.0
Power                                                                      1
Avionics               1    1  110  0.0116  0.01160.208    0.0   0.0
Avionics                                                                   1
Crew Station           1    1  110  0.0058  0.0058  1.50   0.0   0.0
Crew Station                                                               1
Armament               1    1  110  0.0044  0.00440.208    0.0   0.0
Armament                                                                   1
1005000566753          1 0  1   1   .00060  .00060   5.2  0.03        4.0  0.00
1005000566753      X 4.0  0.00       4.0           016.  030.  00029940.
1005000566753N       1     1   1 1          .00060  .083  .00000000  0000
1005000566753N    X 4.0  0.00       4.0            .083   .083   999999.       1
1270010405948          1 0  1   1   .00820  .00820   9.1  0.08        7.0  0.00
1270010405948      X 7.0  0.00       7.0           014.  030.  00050369.
1270010405948N       1     1   1 1          .00820  .083  .00000000  0000
1270010405948N    X 7.0  0.00       7.0            .083   .083   999999.       1
1270010469884          1 0  1   1   .00680  .00680   9.1  0.11        7.0  0.00
```

```
1270010469884     X 7.0 0.00        7.0          014. 030. 00064321.
1270010469884N        1    1   1 1         .00680 .083 .00000000 0000
1270010469884N   X 7.0 0.00        7.0          .083  .083  999999.        1
    .
    .
    .
    .
    .
APPL
1005000566753      BS01  1.00
1270010405948      BS01  1.00
1270010469884      BS01  1.00
    .
    .
    .
    .
    .
VTM
Structure            2  1.00  1.00  1.00  0.00  11111
Flight Center        2  1.00  1.00  1.00  0.00  11111
Propulsion           2  1.00  1.00  1.00  0.00  11111
Fuel                 2  1.00  1.00  1.00  0.00  11111
Power                2  1.00  1.00  1.00  0.00  11111
Avionics             2  1.00  1.00  1.00  0.00  11111
Crew Station         2  1.00  1.00  1.00  0.00  11111
Armament             2  1.00  1.00  1.00  0.00  11111
1005000566753        1  1.00  1.00  1.00  0.00  11111
1005000566753N       2  1.00  1.00  1.00  0.00  11111
1270010405948        1  1.00  1.00  1.00  0.00  11111
1270010405948N       2  1.00  1.00  1.00  0.00  11111
1270010469884        1  1.00  1.00  1.00  0.00  11111
1270010469884N       2  1.00  1.00  1.00  0.00  11111
    .
    .
    .
    .
    .
STK
1005000566753      BS01      0
1270010405948      BS01      9
1270010469884      BS01      7
    .
    .
    .
    .
    .
END
```

F. STATISTICAL TABLES

Most statistics of the data used have been generated by SAS or FORTRAN programs on the VAX. The FORTRAN program LIST-INTVL2 generated the percent cost and the cumulative percent cost, while SAS generated the mean, the sum, the standard deviation, etc. These statistics can be displayed in tabular form by using the INGRES

VAX data base system. Like SAS, INGRES reads data in formatted style and processes and displays the data according to the user's command. INGRES responds to QUEL and SQL command languages in the menu-driven version. The following is a simple procedure that takes the data file CFDAT.DAT (output data list from SAS .LOG file) and creates a table that can be sorted and manipulated to provide other statistics.

1. Procedures for Using Ingres

- Create data base

  >createdb *name*

- Execute menu driven Ingres

  >rtingres *data base name*

- Create table

  From Ingres main menu: choose TABLES

  From TABLES menu: press <1> on number pad to create a table

  From TABLES data menu: enter *table name*

```
input        i2
lru          c17
qpa          i1
fr           c10
xfr          c8
hrfr         c8
cost         f4
xcost        f4
pctxcost     f4
cumptxcost   f4
```

  press <0> on number pad to save

- Exit TABLES menu by pressing PF3 several times until main menu is up.

Note that this table is set up to read the data listing file from the SAS .LOG file (CFDAT.DAT).

- From main menu, choose QUEL

```
copy table name (input=c4, lru=c17, qpa=c4, fr=c10, xfr=c8,
hrfr=c8, cost=c12, xcost=c10, pctxcost=c7, cumptxcost=c8, xxx=d0nl)
from "(full directory filename)"
<enter>
```

  press PF3 when command finishes execution

• Retrieve data in tabular form

From QUEL, clear all previous commands by pressing <4> on the number pad.

```
range of l1 is table name
retrieve (l1.all) or
retrieve (l1.input,l1.lru,..,l1.(any column))
*sort by column name: ascending or descending
<enter>
```

Tabulated data will be output on screen.

*sort by is an optional command in the retrieve command. For more QUEL commands, refer to INGRES Database and Application Systems,Volume One.

• Save tabulated data to file

From the screen output of the tabulated data, go to the bottom of the table by pressing <CTRL> <J>. Press <5> on number pad to write table to a file. Press PF3 several times to exit RTINGRES.

Note that an existing data base, JOE1, contains tables of Dyna-METRIC data of previous studies.

2. Procedures for Creating Statistical Tables on the PC

• Download the desired .DAT files, from the VAX, that have been created after using the DYNAOUT.EXE program, option 2.

• Check each of the .DAT files in a text processor to ensure that the records in the file are in the correct format -- a carriage return at the end of every record, two characters in the first field of every record, no extra carriage returns at the beginning or end of the file.

• In dBase:

USE xxxrel.dbf whose structure is as follows:

Field Name	Type	Width	Dec
DAY	Numeric	2	
SPACE_20	Character	1	
Field Name	Type	Width	Dec
BASE	Character	4	
SPACE	Character	5	
T_NFMC	Numeric	1	
SPACE2	Character	5	

T_ACFT	Numeric	2	
P_NFMC	Numeric	6	3
SPACE3	Character	1	
P_SORTIES	Numeric	6	3
SPACE4	Character	3	
FMC	Numeric	2	
SPACE5	Character	2	
E_NFMC	Numeric	6	3
EP_NFMC	Numeric	6	3
SPACE6	Character	5	
E_SORTIES	Numeric	6	2
SPACE7	Character	2	
E_SRT_A	Numeric	6	3
C_P_NFMC	Numeric	6	3
C_SPACE9	Character	1	
C_P_SORTIE	Numeric	6	3
C_SPACE10	Character	3	
C_FMC	Numeric	2	
C_SPACE11	Character	2	
C_E_NFMC	Numeric	6	3
C_EP_NFMC	Numeric	6	3
C_SPACE12	Character	5	
C_E_SORTIE	Numeric	6	2
C_SPACE13	Character	2	
C_E_SRT_A	Numeric	6	3
TBO	Numeric	10	2

APPEND FROM file.DAT SDF

COPY TO file.dbf

ZAP xxxrel.dbf

Repeat the preceding four steps for every .DAT file.

- In Excel:

FILE OPEN the three reliability level .DBF files related to the same scenario. EDIT COPY them all into one spreadsheet (i.e. BDMD050.DBF, BDMD100.DBF AND BDMD150.DBF could be combined in one spreadsheet called BDMD.WK1)

EDIT DELETE all columns with field names starting with Space.

Add a column to the right end of the spreadsheet labeled SORT-PROG, which contains the sortie goals for the various flying programs:

Standard Scenario	
days 1-3	24*3.13=75.12
days 4-6	24*3.09=74.16
days 7-18	24*1.00=24
days 19-26	24*0.98=23.52
day 30	24*0.97=23.38
Surge Optempo	
days 1-30	24*3.13=75.12
Moderate Surge	
days 1-6	24*3.13=75.12
days 7-30	24*2.08=49.92

Create a column to calculate the number of sorties achieved for days 11, 13, 15, 17, 19, 21, 23, 24, 25, 27, 28, 29 by interpolating from the data in the column labeled C_E_SORTIE. Sum these values.

Add this sum to the sum of the values in the C_E_SORTIE column to result in the total sorties flown over 30 days.

Calculate spares cost per sortie by dividing the spares cost calculated by the Dyna-METRIC model by the total sorties previously calculated.

Repeat last four steps for each reliability level in the spreadsheet.

SAVE AS filename.WK1, OPTIONS WK1. These . WK1 files will be used to generate two type of graphs as described in a subsequent section of this appendix.

G. GENERATE GRAPHICS

Two graphs that are of interest are Sorties or Percent Of Sorties Achieved versus Day of Combat and Cost versus Demand Rate. These graphs are generated by Graphic Outlook on the VAX, and Harvard Graphics on the PC.

1. Summary of Programs

- DYNAOUT.FOR is a FORTRAN program that extracts the flying program data from the output -COMBO.DAT file. This program also extracts the (not fully mission capable (NFMC) level and cost from the -COMBO.DAT file. The output from this program lists the data required in a formatted form, which is used to import into Graphic Outlook for graphics.
- PLOTDATA.WRK is a Graphic Outlook spreadsheet file formatted to read the output from DYNAOUT.FOR into the spreadsheet for plotting.

2. Procedures for Generating Sorties versus Day of Combat Graph on the VAX

Execute DYNAOUT.EXE. The input file required is *filename*-COMBO.DAT file.

>run DYNAOUT

Menu of DYNAOUT.EXE:

(1) GET LISTING OF NFMC AND COST FROM BUY COMBO FILES
(2) GET LISTING OF FLYING PROGRAM FROM EVALUATION COMBO FILES
(3) QUIT

Choose option 2.

Load the output file obtained from DYNAOUT.EXE into Graphic Outlook in PLOTDATA.WRK. Columns A to S will contain the output from DYNAOUT with rows 11 to 28 for normal (100 percent) demand rate, rows 31 to 48 for low (150 percent) demand rate, rows 51 to 68 for high (50 percent) demand rate.

>grlook PLOTDATA

>/fi

choose READ file
from READ FILE TYPES menu, choose option 1
from MENU OF READ_FILE OPTIONS, enter:

2,*file name*.dat (This file is the output file from DYNAOUT)
5, xx (xx=A11 for 100%, xx=A31 for 150%, xx=A51 for 50%)

Note that / denotes Graphic Outlook commands

• Enter sorties profile for evaluation days in column C, row 81 to row 98. Press <!> several times to recalculate all values.

• Set GRAPH PARAMETERS

```
>/gr
```

choose high resolution and option 4 for a line/scatter plot

For a line/scatter plot:

```
TITLE PARAMETER
      size of characters: .20
      y position of title: 5.6

X AXIS PARAMETERS
      * x axis data range: v71:v88
      size of characters on axis: .15

Y AXIS PARAMETERS
      * data 1 range: w71:w88
      data 2 range: x71:x88
      data 3 range: y71:y88
      line types: refer to GRLOOK user's manual
      size of characters on axis: .15

PLOT DIMENSIONS
      set x min, and x max to desired values
      set y min, and y max to desired values

LEGEND PARAMETERS
      x position of legend: 7.0
      y position of legend: 2.0

TERMINAL DESCRIPTION
      output device/file spec: sys$output for screen output
                               filename.out for file output
      port: 5 for screen output
            4 for file output
```

Print graph on laser

First print graph to a file by changing the terminal description on the graph parameters, and exit GRLOOK.

>laserregis ***filename.out***

This command will automatically convert the file for output to the laser.

3. Procedures for Generating Cost versus Demand Rate Graph on the VAX

Note the cost and demand rate level from the outputs of Dyna-METRIC.

- Execute DECGRAPH. DECGRAPH is a graphing utility provided for the VAX from DIGITAL.

  >graph

- Choose the enter data icon. (Refer to DECGRAPH User Manual)

- . Choose the keyboard icon. (Refer to DECGRAPH User Manual)

- Enter data and labels on DECGRAPH data sheet. Change the x-axis to text data by pressing + until "text" appears.

- Exit data sheet by entering the stop icon on the upper left corner. Graph by entering the graph icon. (Refer to DECGRAPH User Manual)

- Create a regis file by first pressing PF1, then <m> when the graph appears on the screen.

- To print the graph on the laser, exit DECGRAPH after creating there gis file and issue command,

  >laserregis *filename*.grm

4. Procedures for Generating Sorties versus Day of Combat Graph on the PC In Harvard Graphics

- CREATE NEW CHART
  BAR/LINE
  X DATA TYPE NUMBER
  Escape back to the Main Menu

- IMPORT/EXPORT
  IMPORT LOTUS DATA
  Choose the appropriate .WK1 file

- Input Ranges (if Excel was used to create .WK1 files)

X Data Range:	A3.A20
Other Ranges:	T3.T20
	Q3.Q20
	Q25.Q42
	Q47.Q64

Append Data: YES

- In the X Axis Numeric column, insert the missing days 0, 11, 13, 15, 17, 19, 21, 23, 24, 25, 27, 28, 29.

- Press F8 for four pages of Titles and Options:

X Axis Title:	Day of Conflict
Y1 Axis Title:	Number of Sorties
Series 1 Name:	SORTIE GOAL
Series 2 Name:	High
Series 3 Name:	Baseline
Series 4 Name:	Low
Type:	LINE for all series
Y1 Grid Lines:	NONE
X Axis:	Minimum Value 0
	Maximum Value 32
	Increment 2
Line Style:	2 for Sortie Goal series

Type appropriate chart titles, subtitles and footnotes.

- Escape to the Main Menu and choose DRAW/ANNOTATE.

g. ADD TEXT to type in the total number of sorties achieved in each reliability level by visually reading these values from the appropriate spreadsheet. ADD TEXT to add Reliability to each X Axis category.

5. Procedures for Generating Cost versus Demand Rate Graph on the PC

In Harvard Graphics:

- CREATE NEW CHART

  BAR/LINE

  X DATA TYPE NAME

Pt 1 Name: HIGH
Pt 2 Name: BASELINE
Pt 3 Name: LOW

• Enter values for the three points by visually reading spares cost per sortie from the appropriate .WK1 spreadsheet.

• Press F8 for four pages of titles and options:

X Axis Title: Reliability
Delete "Series 1"
Y1 Axis: Minimum Value 0
Maximum Value 500
Increment 100

H. AFLC DYNA-METRIC 4.4

Current studies on AFLC's Dyna-METRIC Version 4.4 shows that this version reduces cost by accurately purchasing the level of stocks set and provide some graphical outputs. All future studies will use this new version. The executables for this new version is found on the METRICIII project pack:

```
[GMCBRYDE.DYNAMETRIC.UPDATE1.PART]AFLC-PART
[GMCBRYDE.DYNAMETRIC.UPDATE1.ECHO]AFLC-ECHO
[GMCBRYDE.DYNAMETRIC.UPDATE1.PIPE]AFLC-PIPE
[GMCBRYDE.DYNAMETRIC.UPDATE1.MOD]AFLC-MOD
[GMCBRYDE.DYNAMETRIC.UPDATE1.REPORT]AFLC-REPORT
```

All procedures outlined in this appendix apply to both the AFLC's and RAND's version of Dyna-METRIC.

I. DYNA-METRIC MICROCOMPUTER ANALYSIS SYSTEM

A microcomputer version of Dyna-METRIC Version 4.4 has been implemented as a component of the Dyna-METRIC Microcomputer Analysis System (DMAS) by Dynamics Research Corporation (DRC) of Andover, Massachusetts. During this phase of the effort, the study team acquired the DMAS software and adapted it to run with the base case operating scenario, which is documented in [A-2]. This appendix contains an overview of DMAS and a brief discussion of the study team's adaptation of the software.

DMAS allows unit-level logistics analysts to access and execute Dyna-METRIC 4.4 capabilities to support a variety of resource management decisions within the United States

U.S.Air Force. Because DMAS operates on a standalone microcomputer, the unit commander has immediate access to this analysis tool. DMAS provides the user with the capability of accessing unit-specific data (demand rates, repair times) and basewide sources of on-hand stock quantities that have been extracted from the Standard Base Supply System (SBSS).

The five major functional areas of DMAS are:

- Unit-Level Data base: Allows the user to store, manipulate, and retrieve unit-level scenario, parts, and stock data from any data base.
- SBSS Processing: Processes and stores the data that have been extracted from the SBSS. This capability produces unit-level, on-hand stock data in accordance with user-selected stock allocation schemes (robusting) and base-wide resource categories.
- Dyna-METRIC Version 4.4: Performs capability assessments (wartime or peacetime) and requirements computations.
- Output Reports: Allows the user to display and/or print either DMAS graphs and tables or standard Dyna-METRIC output reports.
- Expert User: Allows the user to import Dyna-METRIC Version 4.4 files, edit the files with a text editor, and perform capability assessments/requirements computations with Dyna-METRIC Version 4.4.

DMAS was designed to support three primary applications. One of the applications provides assessments of wartime sortie capabilities that are supported by available War Readiness Spares Kit/Base Level Self-Sufficiency Spares (WRSK/BLSS) and other base resources. These assessments are based on D029 component data, user-supplied flying hour programs, and all assets available to the wing commander to take to war. This unit level assessment capability offers greater flexibility than current automated assessments that are based on only selected categories of reported, on-hand stock levels. Thus, DMAS can be used to support commanders' assessments of the unit's capability, based on resources not included in standard Weapon System Management Information System assessments.

The second application provides assessments of peacetime sortie capabilities that are supported by available base spares resources. Using a data base of unit-level component data and on-hand stock levels, the unit may not only forecast its ability to execute its monthly flying programs, but may also predict components that may be limiting factors. With this type of information, units can carefully manage potential problem items and anticipate the types of logistic support (prioritized repair, cannibalization, lateral resupply) needed to accomplish the scheduled flying activity.

The third application of DMAS computes spares requirements for unit deployments. Based on the scheduled deployment flying program and unit-level component data, DMAS can provide a preliminary attempt at the deployment kit configuration needed to support the unit. This capability also provides a convenient means of preparing detailed after-action reports.

The version of Dyna-METRIC within DMAS is limited by the amount of available memory on the PC. The default software configuration that is optimized for unit level analysis was not capable of handling the requirements of this study. With the assistance of the software developers at DRC, the IDA study team was able to reconfigure the PC Dyna-METRIC software to accommodate the study requirements. The dimensioning parameters, the maximum size of tables allowed during processing, were modified to accommodate the study team's adaptation of the model for maintenance delay and battle damage.

The software operates as expected but at the maximum capacity of the computer. Using the PC version of the model to study widely varying cases will require separate versions of the model. The recent introduction of new software tools and more advanced hardware will certainly resolve this problem, making the PC version of Dyna-METRIC a viable alternative to the existing mainframe and minicomputer versions.

REFERENCES

C-1 Boren, Patricia M.; Karen E. Isaacson, Raymond Pyles, and Christopher Tsai, *Dyna-METRIC Version 4: ;Modeling Worldwide Logistics Support to Aircraft Components,* Report No. WD-2659-AF, RAND Corporation, June 1985.

C-2 Tyson, Karen, Peter Evanovich, Stanley Horowitz, and D. Graham McBryde, *Weapon Reliability and Logistic Support Costs in a Combat Environment,* IDA Paper No. P-2230, Institute for Defense Analyses, July 1988.

APPENDIX D

PROCEDURES FOR DEVELOPMENT OF SIMULATED DATA SET USING F-15C LINE REPLACEABLE UNITS

A. INTRODUCTION

The purpose of this appendix is to describe the development of simulated data from F-15 Line Replaceable Units (LRUs). As discussed in this paper, the F-15C was analyzed as if it were a new system, using less information than what is available than for current systems. The simulated data set is based on distribution of mean costs and mean failure rates. All other fields, such as Not Repairable This Site (NRTS) rate, condemnation rate, and repair time, are set to the corresponding overall means of the actual data set. The method is based on the work of Ince and Evanovich [Reference D-1].

INTERVAL	RANGE OF VALUES
1	0 to m/8
2	m/8 to m/4
3	m/4 to m/2
4	m/2 to m
5	m to 2m
6	2m to 3m
7	3m to 6m
8	> 6m

For Costs, m = mean cost, in dollars, of the total unique items.

For Failure Rates, m = mean value, of the failures per flying hour, weighted by QPA (Quantity per Aircraft), of the total unique items.

This appendix details how the simulated data set is developed by the Institute of Defense Analyses, based on this distribution.

B. PROCEDURES FOR GENERATING SIMULATED DATA

The following procedures are intended for operations on the VAX. (All programs used in this paper are contained in Reference D-2).

1. Summary of Programs

- LIST-INTVL2.FOR is a FORTRAN program that calculates the mean failure rate, the mean cost, percent extended cost (cost weighted by quantity per aircraft), and cumulative percent extended cost and lists these along with the LRU number, Quantity Per Aircraft (QPA), failure rate, and cost in a formatted data file to be used as an input file for SAS.
- CFTABLE.SAS is an SAS program that produces a frequency distribution matrix of cost and failure rate.
- NEWFILE2.FOR is a FORTRAN program that takes the output of the SAS program and generates the corresponding hypothetical data set in Dyna-METRIC format for the LRU, APPL, and VTM cards.
- FACTOR.FOR is a FORTRAN program that calculates the multiplying factor for a hypothetical data set that contains both hypothetical data and actual data to fit the mean of the original data set.

2. Working Files

The following files must be present at the working directory:

- A Dyna-METRIC data file
- CFTABLE.SAS
- LIST-INTVL2.FOR or LIST-INTVL2.EXE
- NEWFILE2.FOR or NEWFILE2.EXE
- FACTOR.FOR or FACTOR.EXE.

3. Copy CFTABLE.SAS to Data File

>copy cftable.sas *filename*.dat

The copied file is referred to here as *CF1.DAT*.

4. Execute LIST-INTVL2.EXE:

Sample run:

>run LIST-INTVL2.EXE

ENTER THE INPUT FILE NAME (DYNAMETRIC DATA FILE): *>B100*

ENTER THE OUTPUT FILE NAME (DATA LISTING TO BE USED BY SAS):

>filename

ENTER THE FILE NAME OF THE SAS PROGRAM: >*CF1*

The output file is referred to here as *OUTSAS.DAT*.

Note that > denotes the VAX prompt.

The output file *OUTSAS.DAT* will be the following:

1	1005000566753	1	0.00060	29940.00	0.00519	41587.25	8.643	8.643
2	1270010405948	1	0.00820	50369.00	0.00519	41587.25	14.541	23.184
3	1270010469884	1	0.00680	64321.00	0.00519	41587.25	18.569	41.753
4	1270010635567	1	0.00730	124585.00	0.00519	41587.25	35.966	77.719
5	6680011288000PT	2	0.00730	10712.00	0.00519	41587.25	6.185	83.904
6	6685003336763	1	0.00050	415.00	0.00519	41587.25	0.120	84.024
7	6685010482889NT	2	0.00140	2984.00	0.00519	41587.25	1.723	85.747
8	7021004775716	1	0.00070	49372.00	0.00519	41587.25	14.25	100.000

Column 1 is the input index. Column 2 is the LRU number. Column 3 is the QPA. Column 4 is the failure rate. Column 5 is the cost. Column 6 is the mean of the extended failure rate. Column 7 is the mean cost. Column 8 is the percent extended cost, and column 9 is the cumulative percent extended cost. Extended failure rate and extended cost are failure rate and cost weighted by QPA.

5. Edit CF1.DAT

The output file *OUTSAS.DAT* must be entered into the SAS program.This is done in EDT, the VAX editor. The VAX editor is activated by issuing the VAX command EDT or EDIT *filename*.

```
>edit CF1.DAT
*type 2
*s/xxxxx/OUTSAS
*EXIT
```

Note that * denotes EDT command prompt.

6. Execute SAS program.

```
>sas CF1.DAT
```

The execution of the SAS program will generate a .LOG and .LIS output file. The .LOG file will contain an outline of the SAS procedures and errors, if any, and a listing of

LRU, QPA, failure rate, extended failure rate, hours per failure, cost, extended cost, percent extended cost, cumulative percent extended cost, row number of the matrix, column number of the matrix, midvalue of the interval of the cost (row), and midvalue of the interval of the failure rate (column). The .LIS file will contain a frequency distribution of cost by failure rate in a matrix representation from the intervals given previously.

The .LIS file will also contain statistical information such as the mean, standard deviation, minimum value, maximum value, standard error of mean, the sum, and the variance for failure rates and costs as well as a listing of LRU, QPA, failure rates, costs, and the corresponding block location of LRUs in the matrix with its corresponding midvalue of the interval.

A sample matrix follows. For a complete SAS program and the output .LOG and .LIS files, refer to Reference D-2 The following frequency distribution matrix of cost by failure rate is based on the sample data file *B100.DAT*.

Table D-1. Matrix of F-15C LRUs, Categorized by Cost and Failure Rate

X (Cost) Y (Failure rate weighted by QPA)

Frequency	0-0.00054	0.00054-0.00108	0.00108-0.00217	0.00217-0.00433	0.00433-0.00866	0.00866-0.01300	0.01300-0.02599	<0.02599
0-2258.93	41	24	29	19	15	6	7	3
2258.93-4517	18	15	14	15	6	2	2	1
4517.86-9035	10	15	15	5	5	1	5	0
9035.72-18071	6	7	11	7	6	0	2	0
18071.44-36142	1	7	6	9	7	3	1	0
36142.88-54214	1	3	1	4	2	1	0	2
54214.32-108428	0	3	1	1	4	1	1	3
> 108428.64	0	0	1	3	4	3	2	0
Total	77	74	78	63	49	17	20	9

From the matrix, it can be determined that 41 LRU items have costs ranging from 0 to 2258.93 and failure rates ranging from 0 to 0.00054, 24 LRU items have costs between 0 and 2258.93 and failure rates between 0.00054 to 0.00108, 29 LRU items have costs ranging from 0 to 2258.93 and failure rates ranging from 0.00108 to 0.00217. New assignments of costs and failure rates for the LRU items will be based on the midvalue of the interval in which they fall -- the LRU items that fall in the cost range of 0 to 2258.93

and failure rate range of 0 to 0.00054 will have an assigned cost of 1129.46 and have an assigned failure rate of 0.00027; the LRU items that fall in the cost range of 0 to 2258.93 and have a failure rate range of 0.00054 to 0.00108 will have an assigned cost of 1129.46 and have an assigned failure rate of 0.00081, and so forth. For distributions that have items in the last interval that provides no upper bound for determination of midvalues, the costs and failure rates that fall in the last interval will have assigned values determined by the following calculated values:

$$\text{For Cost} \quad C = \frac{\sum^{i} \text{Cost} - \sum^{j} \text{Midcost}}{NR}$$

C: assigned value of cost for LRU items that fall in the last interval

Cost: the cost from the original data

Midcost: the midvalue of cost of each interval

NR: total number of items in the last row.

$$\text{For Failure Rate: } FFR = \frac{\sum^{i} FR\text{x}QPA - \sum^{j} \text{MidFR}}{NC}$$

FFR: assigned value of failure rate for LRU items that fall in the last interval

FR: the failure rate from the original data

QPA: quantity per aircraft from the original data

MidFR: the midvalue of failure rate of each interval

NC: Total number of items in the last column.

NOTE: This calculation is done in the fortran program NEWFILE2.FOR.

7. Create Data File from SAS .LOG Output File:

>edit *CF1.LOG*

Using EDT, cut out the listing portion of the data and copy the cut out section to another file. The cut command in EDT is activated by first selecting the portion of text to be cut. The select is activated by pressing <.> on the number pad. Moving the cursor after activating the select mode highlights the text being selected. After the selection of text, the highlighted portions can be cut out by pressing <6> on the number pad. The highlighted text is then saved in the EDT buffer. (The buffer can be written out by issuing EDT command WRITE.) Activate the EDT command mode by pressing <CTRL> followed by <Z> on the keyboard or <PF1> followed by <7> on the number pad to get the * prompt or the COMMAND prompt respectively.

***write *filename*.dat =paste.**

The new data listing file will be called *CFDAT.DAT* here. Edit this file in EDT to take out all the titles and blanks lines.

CFDAT.DAT will be the following:

1	1005000566753	1	0.00060	0.00060	1666.67	29940.00	29940.00	0.352	0.352	5	2
2	1270010405948	1	0.00820	0.00820	121.951	50369.00	50369.00	0.592	0.945	6	5
3	1270010469884	1	0.00680	0.00680	147.059	64321.00	64321.00	0.756	1.701	7	5
4	1270010635567	1	0.00730	0.00730	136.986	124585.00	124585.00	1.465	3.166	8	5
5	1270011838987	1	0.01050	0.01050	95.2381	77474.00	77474.00	0.911	4.077	7	6
6	1280010423952	1	0.01120	0.01120	89.2857	37610.00	37610.00	0.442	4.520	6	6
7	1560010037178FX	1	0.00110	0.00110	909.091	78621.00	78621.00	0.925	5.444	7	3
8	1650003337185	2	0.00140	0.00280	357.143	3340.00	6680.00	0.079	5.523	2	4
9	1650010503491	1	0.00070	0.00070	1428.57	42364.00	42364.00	0.498	6.021	6	2
10	1650010653500FS	2	0.00080	0.00160	625	3654.00	7308.00	0.086	6.107	2	3
11	1680010325251	1	0.00150	0.00150	666.67	19667.00	19667.00	0.231	6.338	5	3
12	1680010473179FX	1	0.00170	0.00170	588.235	17360.00	17360.00	0.204	6.543	4	3

1	27107.2	0.00081
2	45178.6	0.00650
3	81321.5	0.00650
4	0.00000	0.00650
5	81321.5	0.01083
6	45178.6	0.01083
7	81321.5	0.00162
8	3388.4	0.00325
9	45178.6	0.00081
10	3388.4	0.00162
11	27107.2	0.00162
12	13553.6	0.00162

•
•
•
•

8. Execute NEWFILE2.EXE:

The FORTRAN program NEWFILE2.FOR will generate the new Dyna-METRIC data file from files *B100.DAT* and *CFDAT.DAT*.

>run NEWFILE2.EXE

ENTER FILE NAME OF DYNAMETRIC DATA FILE: *>B100*

ENTER FILE NAME OF SAS OUTPUT FILE: *>CFDAT*

ENTER FILE NAME OF OUTPUT FILE: (NEW DATA SET IN DYNAMETRIC FORMAT) *>filename*

The output file will be called *FB100.DAT* here.

FB100.DAT. is a complete set of hypothetical data where all LRU items are assigned as RR items. The following is a sample LRU data card from FB100.DAT.

```
5201                1 0  1  1 0.000810.00081  5.5 0.68        5.4 0.00
5201           X 5.4 0.00        5.4             15.  30. 27107.20
```

The hypothetical LRU number 5201 corresponds to the first item that falls in the fifth interval of cost and the second interval of failure rate. The hypothetical failure rate 0.00081 is the mid-value of the second interval of failure rate, and the hypothetical cost of 27107.20 is the mid-value of the fifth interval of cost. All other fields of data such as lone base repair time (5.5), lone base NRTS rate (0.68), cirf-served base NRTS rate (5.4), cirf-served base condemnation rate (0.00), cirf repair time (5.4), cirf NRTS rate (0.00), depot repair time (5.4), peacetime resupply time (15.), and wartime resupply time (30.) are the means from the actual data set.

C. PROCEDURES FOR GENERATING SIMULATED DATA WITH ACTUAL AND SIMULATED DATA

For the sample data set, the remove, repair, and replace (RRR) items tended to be higher cost and higher failure rate items; therefore, LRU items that fell in the lower 3-by-3 block were mostly RRR items. These items retained their original data attributes. Items that fell outside the lower 3-by-3 block were assigned as remove and repair (RR) items and contain cost, failure rate, and all other data such as NRTS rates, condemnation rate, and repair time of simulated data discussed previously. The RR items were further modified so that the mean of the cost and failure rate reflects the mean of the cost and failure rate of the original data set. The multiplication factor for the RR items is expressed by:

$$\text{For Cost } CF = \frac{\sum Cost_i - \sum Cost_j}{\sum Cost_k}$$

CF: multiplication factor for the hypothetical cost M

$Cost_i$: cost of assigned RR and RRR items

$Cost_j$: cost of assigned RRR items

$Cost_k$: cost of assigned RR items

For Failure Rate: $FFRF = \dfrac{\sum FR_i QPA_i - \sum FR_j QPA_j}{\sum FR_k QPA_k}$

FFRF: multiplication factor for the hypothetical failure rate for RR items

FR_i: failure rate of assigned RR and RRR items

FR_j: failure rate of assigned RRR items

FR_k: failure rate of assigned RR items

QPA_i: quantity per aircraft of RR and RRR items

QPA_j: quantity per aircraft of RRR items

QPA_k: quantity per aircraft of RR items

Note that these calculations are done by the program FACTOR.FOR.

1. Create a Complete Simulated Data Set As Discussed in B

2. Observe Location of LRUs in Matrix

Determine which actual LRUs fall in the RRR block. The SAS listing file (*CFDAT.DAT*) shows the location of LRUs in the matrix (x: the row number of the matrix, and y: the column number of the matrix), and the SAS .LIS file show the intervals of the matrix.

3. Locate LRUs in Actual Data Set

From the actual data set, create a file of LRU, APPL, and VTM data of the LRUs of b. To create the file, use EDT's cut and paste. Cut and append the desired LRUs, APPL, and VTM data and write the cut buffer to another file by

***write *filename.dat* =paste**

4. Edit Simulated Data Set

Edit the complete simulated data set in EDT. Delete the simulated LRUs that fall in the RRR block of the matrix from the LRU, APPL,and VTM portion, and replace with the actual LRUs from the file created in 3. The actual LRU file can be called in EDT by

include *filename.dat

Exit EDT with another filename to create the new file.

exit *filename.dat

This new file will be called FB1001.DAT here.

FB1001.DAT will have the following sample LRU data cards

```
5201                    1 0  1 1 0.00081  0.00081  5.5 0.68       5.4 0.00
5201              X 5.4 0.00     5.4          15.  30. 27107.20
5841010630855          1 0  1 1 0.010400.01040 9.1 0.02        7.00 0.00
5841010630855    X 7.0 0.00        7.0             14.  30. 340306.
```

The hypothetical LRU item 5201 is outside the RRR block of the matrix and thus contains simulated data attributes. LRU item 5841010630855 replaces hypothetical LRU item 8601, which fell in the RRR block of the matrix, and contains data from the actual data set.

5. Adjust Simulated Data

Execute FACTOR.EXE to adjust the simulated data portion.

>run FACTOR.EXE

ENTER THE NAME OF THE SIMULATED DATA FILE THAT CONTAINS SIMULATED AND

ACTUAL DATA: >*FB1001*

ENTER A NAME FOR THE NEW SIMULATED DATA FILE: >*filename*

ENTER THE TOTAL SUM OF THE EXTENDED FAILURE RATE: >*1.676* (Value obtained from SAS .LIS file)

ENTER THE TOTAL SUM OF THE COST: >*6993647.00* Value obtained from SAS .LIS file)

THE NEW SIMULATED DYNAMETRIC DATA FILE IS *filename* .DAT

The output file name will be called *NFB100.DAT* here.

NFB100.DAT is a modified version of FB100.DAT data set in which the simulated failure rates and costs are multiplied by a calculated factor which will cause the means of failure rate and cost to reflect the mean of failure rate and cost of the actual data set. The following are sample data cards from NFB100.DAT.

```
5201                    1 0  1  1 0.000780.00078  5.5 0.68       5.4 0.00
5201              X 5.4 0.00      5.4          15.  30. 26521.87
5841010630855     1 0  1 1 0.010400.0104 9.1 0.02          7.00 0.00
```

5841010630855 X 7.0 0.00 7.0 14. 30. 340306

Simulated LRU item 5201 now contains an adjusted failure rate from 0.00081 to 0.00078 and an adjusted cost from 27101.20 to 26521.87. LRU item 5841010630855 retains its actual data attributes and is not adjusted.

REFERENCES

D-1 Ince, John F; and Evanovich Peter; *Timely Analysis of the Readiness of New Systems,* Report No. CRM 86-119, Center for Naval Analyses, June 1986.

D-2 Eng, Meiling; *VAX and PC Documentations on Simulated Data Analyses and Execution Procedures for Dyna-METRIC,* Institute for Defense Analyses.

D-3 Boren, Patricia H; Isaacson Karen E; Pyles Raymond; and Tsai Christopher; *Modeling Worldwide Logistics Support to Aircraft Components,* Report No. WD-2659-AF, RAND Corporation, June 1985.

APPENDIX E

LISTING OF F-15C PACIFIC AIR FORCE LINE REPLACEABLE UNITS USED IN THE ANALYSIS

This table is a listing of component-related data from the input data set. Column 1 lists the component part name; column 2 identifies the type of component along with the assigned input number. L indicates an LRU component, S indicates an SRU component, and SS indicates a sub SRU component. Column 3 specifies whether CIRF repair facilities are available for that component. Column 4 specifies when to decide to classify a component as not repairable this site (NRTS) or condemn the part, either before or after testing. Column 5 is the cost of buying an additional unit of stock of the component. Column 6 specifies the onshore and offshore bases' peacetime demand rate per flying hour. Column 7 specifies the level of repair, where BASE indicates that the component can be repaired at a base, CIRF indicates that the component can be repaired at CIRF, and DEPOT indicates the component can be repaired at depot. Column 8 specifies the peacetime and wartime resupply time, in days of the expected time for the highest echelon that repairs the component to procure a replacement during either peacetime or wartime.

Table E-1. Detailed LRU Information for F-15C PACAF

PART NAME	NUMBER	CAN TEST AT CIRF?	NRTS OR CONDEMN	COST	DEMANDS PER FLYING HOUR ONSHORE	DEMANDS PER FLYING HOUR OFFSHORE	LEVEL OF REPAIR	RESUPPLY (DAYS) PEACE	RESUPPLY (DAYS) WAR
1005000566753	L 1	NO	AFTER TEST	29940.	0.00060	0.00060	BASE	16.0	30.0
1270010405948	L 2	NO	AFTER TEST	50369.	0.00820	0.00820	BASE	14.0	30.0
1270010469884	L 3	NO	AFTER TEST	64321.	0.00680	0.00680	BASE	14.0	30.0
1270010635567	L 4	NO	AFTER TEST	124585.	0.00730	0.00730	BASE	14.0	30.0
1270011838987	L 5	NO	AFTER TEST	77474.	0.01050	0.01050	BASE	14.0	30.0
1280010423952	L 6	NO	AFTER TEST	37610.	0.01120	0.01120	BASE	14.0	30.0
1560010037178FX	L 7	NO	AFTER TEST	78621.	0.00110	0.00110	BASE	25.0	30.0
1650003337185	L 8	NO	AFTER TEST	3340.	0.00140	0.00140	BASE	11.0	30.0
1650010503491	L 9	NO	AFTER TEST	42364.	0.00070	0.00070	BASE	14.0	30.0
1650010653500FS	L 10	NO	AFTER TEST	3654.	0.00080	0.00080	BASE	14.0	30.0
1680010325251	L 11	NO	AFTER TEST	19667.	0.00150	0.00150	BASE	14.0	30.0
1680010473179FX	L 12	NO	AFTER TEST	17360.	0.00170	0.00170	BASE	14.0	30.0
5821001387991	L 13	NO	AFTER TEST	4729.	0.00590	0.00590	BASE	16.0	30.0
5821011365467	L 14	NO	AFTER TEST	5741.	0.00420	0.00420	BASE	16.0	30.0
5821011369512	L 15	NO	AFTER TEST	5044.	0.00590	0.00590	BASE	16.0	30.0
5826002625018	L 16	NO	AFTER TEST	9318.	0.00070	0.00070	BASE	8.0	30.0
5826010121938	L 17	NO	AFTER TEST	1865.	0.00520	0.00520	BASE	19.0	30.0
5826010211744	L 18	NO	AFTER TEST	8240.	0.00140	0.00140	BASE	14.0	30.0
5836010512886CX	L 19	NO	AFTER TEST	2586.	0.04050	0.04050	BASE	16.0	30.0
5841010032850	L 20	NO	AFTER TEST	67308.	0.00500	0.00500	BASE	14.0	30.0
5841010486312	L 21	NO	AFTER TEST	102078.	0.00640	0.00640	BASE	14.0	30.0
5841010588862	L 22	NO	AFTER TEST	12465.	0.00050	0.00050	BASE	14.0	30.0
5841010603721	L 23	NO	AFTER TEST	277457.	0.00750	0.00750	BASE	14.0	30.0
5841010630855	L 24	NO	AFTER TEST	340306.	0.01040	0.01040	BASE	14.0	30.0
5841011007363	L 25	NO	AFTER TEST	397056.	0.01430	0.01430	BASE	14.0	30.0
5841011234126	L 26	NO	AFTER TEST	151639.	0.00430	0.00430	BASE	14.0	30.0
5841011331822	L 27	NO	AFTER TEST	394321.	0.00760	0.00760	BASE	14.0	30.0
5841011356194	L 28	NO	AFTER TEST	239604.	0.01120	0.01120	BASE	14.0	30.0
5841011582818	L 29	NO	AFTER TEST	403587.	0.00620	0.00620	BASE	14.0	30.0
5865004775704EW	L 30	NO	AFTER TEST	2122.	0.00090	0.00090	BASE	17.0	30.0
5865010131798EW	L 31	NO	AFTER TEST	1632.	0.00010	0.00010	BASE	16.0	30.0
5865010456276EW	L 32	NO	AFTER TEST	93682.	0.03630	0.03630	BASE	19.0	30.0
5865010548810EW	L 33	NO	AFTER TEST	32349.	0.00580	0.00580	BASE	20.0	30.0
5865010668075EW	L 34	NO	AFTER TEST	91545.	0.03900	0.03900	BASE	11.0	30.0
5865010891745EW	L 35	NO	AFTER TEST	22566.	0.00200	0.00200	BASE	14.0	30.0
5865010891808EW	L 36	NO	AFTER TEST	77072.	0.00790	0.00790	BASE	13.0	30.0
5865011003768EW	L 37	NO	AFTER TEST	59193.	0.01870	0.01820	BASE	[illegible]	30.0
5865011003769EW	L 38	NO	AFTER TEST	7061.	0.00070	0.00070	BASE	21.0	30.0
5865011003770EW	L 39	NO	AFTER TEST	80985.	0.02550	0.02550	BASE	13.0	30.0
5865011003771EW	L 40	NO	AFTER TEST	7036.	0.00200	0.00200	BASE	30.0	30.0
5865011003830EW	L 41	NO	AFTER TEST	18725.	0.00080	0.00080	BASE	9.0	30.0
5865011142469EW	L 42	NO	AFTER TEST	16053.	0.00140	0.00140	BASE	14.0	30.0
5865011360443EW	L 43	NO	AFTER TEST	43247.	0.04970	0.04970	BASE	11.0	30.0
5865011449320EW	L 44	NO	AFTER TEST	160776.	0.01110	0.01110	BASE	10.0	30.0
5865012112335EW	L 45	NO	AFTER TEST	43247.	0.04470	0.04470	BASE	14.0	30.0
5895003278781	L 46	NO	AFTER TEST	2814.	0.00210	0.00210	BASE	11.0	30.0
5895003409619	L 47	NO	AFTER TEST	4198.	0.00110	0.00110	BASE	14.0	30.0
5895010162209	L 48	NO	AFTER TEST	38700.	0.00420	0.00420	BASE	14.0	30.0
5895010963727	L 49	NO	AFTER TEST	[illegible]4025.	0.00200	0.00200	BASE	17.0	30.0
5895011126380	L 50	NO	AFTER TEST	19570.	0.01370	0.01370	BASE	16.0	30.0
5895011349225	L 51	NO	AFTER TEST	26780.	0.00800	0.00800	BASE	14.0	30.0

Table E-1. Detailed LRU Information for F-15C PACAF (Continued)

6110005390411	L	52	NO	AFTER TEST	3193.	0.00030	0.00030	BASE	14.0	30.0
6110010498639	L	53	NO	AFTER TEST	4817.	0.00140	0.00140	BASE	14.0	30.0
6605010848224	L	54	NO	AFTER TEST	22145.	0.00530	0.00530	BASE	14.0	30.0
6605010940775	L	55	NO	AFTER TEST	22544.	0.00740	0.00740	BASE	14.0	30.0
6605010954208	L	56	NO	AFTER TEST	139222.	0.02040	0.02040	BASE	14.0	30.0
6610001226625	L	57	NO	AFTER TEST	19972.	0.00440	0.00440	BASE	14.0	30.0
6610001491134	L	58	NO	AFTER TEST	32459.	0.00890	0.00890	BASE	13.0	30.0
6610010903390	L	59	NO	AFTER TEST	22660.	0.00330	0.00330	BASE	10.0	30.0
6610011694770	L	60	NO	AFTER TEST	23936.	0.00400	0.00400	BASE	14.0	30.0
1005001886968	L	61	NO	AFTER TEST	2175.	0.01400	0.01400	BASE	14.0	30.0
1005001886969	L	62	NO	AFTER TEST	2908.	0.00550	0.00550	BASE	14.0	30.0
1005002790528	L	63	NO	AFTER TEST	3529.	0.02120	0.02120	BASE	14.0	30.0
1005019429740	L	64	NO	AFTER TEST	44487.	0.00410	0.00410	BASE	14.0	30.0
1005010932225	L	65	NO	AFTER TEST	5012.	0.00500	0.00500	BASE	14.0	30.0
1005011055476	L	66	NO	AFTER TEST	10475.	0.00220	0.00220	BASE	14.0	30.0
1095001664286	L	67	NO	AFTER TEST	2888.	0.00050	0.00050	BASE	16.0	30.0
1280010315802	L	68	NO	AFTER TEST	638.	0.00030	0.00030	BASE	11.0	30.0
1280010524811	L	69	NO	AFTER TEST	2018.	0.00100	0.00100	BASE	14.0	30.0
1280010542853	L	70	NO	AFTER TEST	481.	0.00040	0.00040	BASE	16.0	30.0
1280010542856	L	71	NO	AFTER TEST	495.	0.00030	0.00030	BASE	15.0	30.0
1280011354647	L	72	NO	AFTER TEST	29648.	0.01060	0.01060	BASE	14.0	30.0
1440010595257BL	L	73	NO	AFTER TEST	37521.	0.00080	0.00080	BASE	14.0	30.0
1440010891384AB	L	74	NO	AFTER TEST	1514.	0.00200	0.00200	BASE	14.0	30.0
1560005186889FX	L	75	NO	AFTER TEST	20148.	0.00060	0.00060	BASE	14.0	30.0
1560005235267FX	L	76	NO	AFTER TEST	24334.	0.00060	0.00060	BASE	14.0	30.0
1560010145787FX	L	77	NO	AFTER TEST	25576.	0.00140	0.00140	BASE	14.0	30.0
1560010564844FX	L	78	NO	AFTER TEST	52188.	0.00050	0.00050	BASE	14.0	30.0
1560010753550FX	L	79	NO	AFTER TEST	2961.	0.00060	0.00060	BASE	13.0	30.0
1560011426673FX	L	80	NO	AFTER TEST	17999.	0.00030	0.00030	BASE	14.0	30.0
1560011825949FX	L	81	NO	AFTER TEST	16424.	0.00050	0.00050	BASE	14.0	30.0
1620002671046	L	82	NO	AFTER TEST	15413.	0.00060	0.00060	BASE	9.0	30.0
1620010362895	L	83	NO	AFTER TEST	3885.	0.00030	0.00030	BASE	14.0	30.0
1620010627002	L	84	NO	AFTER TEST	48153.	0.00060	0.00060	BASE	14.0	30.0
1620011670999	L	85	NO	AFTER TEST	69525.	0.00060	0.00060	BASE	14.0	30.0
1620011671000	L	86	NO	AFTER TEST	69525.	0.00060	0.00060	BASE	14.0	30.0
1630003934771	L	87	NO	AFTER TEST	5944.	0.00060	0.00060	BASE	20.0	30.0
1630010182004	L	88	NO	AFTER TEST	4223.	0.00140	0.00140	BASE	16.0	30.0
1630010585912	L	89	NO	AFTER TEST	6064.	0.01080	0.01080	BASE	14.0	30.0
1630010597069	L	90	NO	AFTER TEST	15238.	0.00250	0.00250	BASE	14.0	30.0
1630010645095	L	91	NO	AFTER TEST	891.	0.00070	0.00070	BASE	17.0	30.0
1630010716112	L	92	NO	AFTER TEST	1810.	0.00890	0.00890	BASE	14.0	30.0
1650002886044	L	93	NO	AFTER TEST	7916.	0.00090	0.00090	BASE	14.0	30.0
1650002952369	L	94	NO	AFTER TEST	8573.	0.00140	0.00140	BASE	14.0	30.0
1650003035851	L	95	NO	AFTER TEST	1782.	0.00030	0.00030	BASE	15.0	30.0
1650003550211	L	96	NO	AFTER TEST	7486.	0.00110	0.00110	BASE	9.0	30.0
1650003550213	L	97	NO	AFTER TEST	19915.	0.00040	0.00040	BASE	15.0	30.0
1650003715854	L	98	NO	AFTER TEST	1545.	0.00060	0.00060	BASE	12.0	30.0
1650004330145	L	99	NO	AFTER TEST	5886.	0.00060	0.00060	BASE	13.0	30.0
1650005168603	L	100	NO	AFTER TEST	2912.	0.00020	0.00020	BASE	12.0	30.0
1650005316029	L	101	NO	AFTER TEST	10974.	0.00170	0.00170	BASE	10.0	30.0
1650005405573	L	102	NO	AFTER TEST	352.	0.00000	0.00000	BASE	23.0	30.0
1650010045794	L	103	NO	AFTER TEST	5013.	0.00030	0.00030	BASE	12.0	30.0
1650010181073	L	104	NO	AFTER TEST	4973.	0.00020	0.00020	BASE	21.0	30.0
1650010189089	L	105	NO	AFTER TEST	13907.	0.00160	0.00160	BASE	14.0	30.0
1650010206212	L	106	NO	AFTER TEST	9600.	0.00090	0.00090	BASE	9.0	30.0
1650010208093	L	107	NO	AFTER TEST	5156.	0.00050	0.00050	BASE	9.0	30.0
1650010297620	L	108	NO	AFTER TEST	3477.	0.00030	0.00030	BASE	13.0	30.0

Table E-1. Detailed LRU Information for F-15C PACAF (Continued)

1650010350799	L 109	NO	AFTER TEST	4024.	0.00090	0.00090	BASE	15.0	30.0
1650010505228	L 110	NO	AFTER TEST	5248.	0.00090	0.00090	BASE	12.0	30.0
1650010520916	L 111	NO	AFTER TEST	12921.	0.00070	0.00070	BASE	16.0	30.0
1650010657768	L 112	NO	AFTER TEST	24875.	0.00210	0.00210	BASE	13.0	30.0
1650010912313	L 113	NO	AFTER TEST	11372.	0.00080	0.00080	BASE	14.0	30.0
1650010964603	L 114	NO	AFTER TEST	38831.	0.00190	0.00190	BASE	14.0	30.0
1650011055523	L 115	NO	AFTER TEST	39564.	0.00220	0.00220	BASE	14.0	30.0
1650011215786	L 116	NO	AFTER TEST	10193.	0.00060	0.00060	BASE	8.0	30.0
1650011216981	L 117	NO	AFTER TEST	7246.	0.00060	0.00060	BASE	14.0	30.0
1650011226948	L 118	NO	AFTER TEST	14706.	0.00040	0.00040	BASE	13.0	30.0
1650011537932	L 119	NO	AFTER TEST	5026.	0.00040	0.00040	BASE	14.0	30.0
1650011739697	L 120	NO	AFTER TEST	158593.	0.00140	0.00140	BASE	14.0	30.0
1660001239568	L 121	NO	AFTER TEST	946.	0.00010	0.00010	BASE	21.0	30.0
1660001239583	L 122	NO	AFTER TEST	893.	0.00010	0.00010	BASE	13.0	30.0
1660001239587	L 123	NO	AFTER TEST	1752.	0.00060	0.00060	BASE	14.0	30.0
1660002381362BO	L 124	NO	AFTER TEST	2265.	0.00090	0.00090	BASE	12.0	30.0
1660002738669	L 125	NO	AFTER TEST	14214.	0.00240	0.00240	BASE	14.0	30.0
1660002876868	L 126	NO	AFTER TEST	1501.	0.00170	0.00170	BASE	11.0	30.0
1660002885532	L 127	NO	AFTER TEST	1074.	0.00010	0.00010	BASE	13.0	30.0
1660002929104	L 128	NO	AFTER TEST	2511.	0.00050	0.00050	BASE	12.0	30.0
1660003277052	L 129	NO	AFTER TEST	5651.	0.00140	0.00140	BASE	14.0	30.0
1660003679453	L 130	NO	AFTER TEST	839.	0.00020	0.00020	BASE	13.0	30.0
1660005678852BO	L 131	NO	AFTER TEST	1952.	0.00480	0.00480	BASE	13.0	30.0
1660007980235	L 132	NO	AFTER TEST	634.	0.00010	0.00010	BASE	19.0	30.0
1660010040798	L 133	NO	AFTER TEST	6529.	0.00050	0.00050	BASE	11.0	30.0
1660010155017	L 134	NO	AFTER TEST	2965.	0.00230	0.00230	BASE	14.0	30.0
1660010214822	L 135	NO	AFTER TEST	4668.	0.00170	0.00170	BASE	14.0	30.0
1660010215625	L 136	NO	AFTER TEST	2118.	0.00200	0 00200	BASE	12.0	30.0
1660010359636TP	L 137	NO	AFTER TEST	17747.	0.00240	0.00240	BASE	14.0	30.0
1660010619097	L 138	NO	AFTER TEST	1105.	0.00050	0.00050	BASE	14.0	30.0
1660010631213	L 139	NO	AFTER TEST	24703.	0.00070	0.00070	BASE	14.0	30.0
1660010808229	L 140	NO	AFTER TEST	10375.	0.00280	0.00280	BASE	14.0	30.0
1660011374105	L 141	NO	AFTER TEST	15285.	0.00110	0.00110	BASE	14.0	30.0
1680001238168	L 142	NO	AFTER TEST	4893.	0.00050	0.00050	BASE	14.0	30.0
1680001323272	L 143	NO	AFTER TEST	9570.	0.00020	0.00020	BASE	14.0	30.0
1680002988837	L 144	NO	AFTER TEST	7234.	0.00020	0.00020	BASE	14.0	30.0
1680003141930	L 145	NO	AFTER TEST	1259.	0.00140	0.00140	BASE	14.0	30.0
1680010041244FX	L 146	NO	AFTER TEST	17659.	0.00080	0.00080	BASE	14.0	30.0
1680010485183	L 147	NO	AFTER TEST	3438.	0.00080	0.00080	BASE	14.0	30.0
1680010524890	L 148	NO	AFTER TEST	4635.	0.00010	0.00010	BASE	10.0	30.0
1680010530071LS	L 149	NO	AFTER TEST	4120.	0.00020	0.00020	BASE	11.0	30.0
1680010652355	L 150	NO	AFTER TEST	3151.	0.00030	0.00030	BASE	18.0	30.0
1680010946707	L 151	NO	AFTER TEST	3716.	0.00020	0.00020	BASE	14.0	30.0
1680011390166	L 152	NO	AFTER TEST	3614.	0.00110	0.00110	BASE	14.0	30.0
1680011625850FX	L 153	NO	AFTER TEST	21309.	0.00080	0.00080	BASE	14.0	30.0
2620010632361	L 154	NO	AFTER TEST	139.	0.02170	0.02170	BASE	32.0	30.0
2620011486221	L 155	NO	AFTER TEST	274.	0.05060	0.05060	BASE	59.0	30.0
2835003901834	L 156	NO	AFTER TEST	3472.	0.00260	0.00260	BASE	14.0	30.0
2835010207249	L 157	NO	AFTER TEST	38574.	0.00180	0.00180	BASE	14.0	30.0
2835010346948	L 158	NO	AFTER TEST	171108.	0.00360	0.00360	BASE	14.0	30.0
2835010881009	L 159	NO	AFTER TEST	33321.	0.00100	0.00100	BASE	11.0	30.0
2835010912433	L 160	NO	AFTER TEST	102205.	0.00290	0.00290	BASE	14.0	30.0
2840003275432PT	L 161	NO	AFTER TEST	6387.	0.00020	0.00020	BASE	13.0	30.0
2840005232036PT	L 162	NO	AFTER TEST	119.	0.00200	0.00200	BASE	14.0	30.0
2840005341824PT	L 163	NO	AFTER TEST	474.	0.00020	0.00020	BASE	14.0	30.0
2840010491150PT	L 164	NO	AFTER TEST	19761.	0.00240	0.00240	BASE	14.0	30.0
2840011028596FT	L 165	NO	AFTER TEST	4882.	0.00050	0.00050	BASE	14.0	30.0

Table E-1. Detailed LRU Information for F-15C PACAF (Continued)

2840011288348PT	L 166	NO	AFTER TEST	604.	0.00170	0.00170	BASE	8.0	30.0
2840011288349PT	L 167	NO	AFTER TEST	349.	0.00100	0.00100	BASE	14.0	30.0
2840011288437PT	L 168	NO	AFTER TEST	6191.	0.00220	0.00220	BASE	20.0	30.0
2840011291044PT	L 169	NO	AFTER TEST	437.	0.00160	0.00160	BASE	12.0	30.0
2840011433254PT	L 170	NO	AFTER TEST	443.	0.00100	0.00100	BASE	15.0	30.0
2840011471898PT	L 171	NO	AFTER TEST	3976.	0.00020	0.00020	BASE	10.0	30.0
2840011471899PT	L 172	NO	AFTER TEST	4090.	0.00050	0.00050	BASE	15.0	30.0
2840011559148PT	L 173	NO	AFTER TEST	1571.	0.00070	0.00070	BASE	14.0	30.0
2840011649087PT	L 174	NO	AFTER TEST	2577.	0.00010	0.00010	BASE	14.0	30.0
2840011802935PT	L 175	NO	AFTER TEST	350.	0.00040	0.00040	BASE	29.0	30.0
2840011802941PT	L 176	NO	AFTER TEST	547.	0.00040	0.00040	BASE	14.0	30.0
2915003353183	L 177	NO	AFTER TEST	1092.	0.00030	0.00030	BASE	14.0	30.0
2915005370336	L 178	NO	AFTER TEST	4634.	0.00010	0.00010	BASE	20.0	30.0
2915010097932	L 179	NO	AFTER TEST	562.	0.00110	0.00110	BASE	14.0	30.0
2915010350276PT	L 180	NO	AFTER TEST	17187.	0.00190	0.00190	BASE	14.0	30.0
2915010353771PT	L 181	NO	AFTER TEST	1830.	0.00020	0.00020	BASE	10.0	30.0
2915010562716	L 182	NO	AFTER TEST	4841.	0.00040	0.00040	BASE	14.0	30.0
2915010553149	L 183	NO	AFTER TEST	1002.	0.00140	0.00140	BASE	14.0	30.0
2915010658525	L 184	NO	AFTER TEST	5223.	0.00070	0.00070	BASE	10.0	30.0
2915010659589PT	L 185	NO	AFTER TEST	25853.	0.00150	0.00150	BASE	14.0	30.0
2915010718325PT	L 186	NO	AFTER TEST	5071.	0.00020	0.00020	BASE	14.0	30.0
2915010753518PT	L 187	NO	AFTER TEST	35123.	0.00210	0.00210	BASE	13.0	30.0
2915010819055PT	L 188	NO	AFTER TEST	5371.	0.00080	0.00080	BASE	14.0	30.0
2915010970518	L 189	NO	AFTER TEST	1347.	0.00080	0.00080	BASE	31.0	30.0
2915011076177PT	L 190	NO	AFTER TEST	11064.	0.00060	0.00060	BASE	14.0	30.0
2915011160968	L 191	NO	AFTER TEST	1192.	0.00170	0.00170	BASE	14.0	30.0
2915011376551PT	L 192	NO	AFTER TEST	7195.	0.00100	0.00100	BASE	14.0	30.0
2915011620998PT	L 193	NO	AFTER TEST	35799.	0.00350	0.00350	BASE	14.0	30.0
2915011699461	L 194	NO	AFTER TEST	435.	0.00020	0.00020	BASE	14.0	30.0
2915011783445	L 195	NO	AFTER TEST	5987.	0.00090	0.00090	BASE	14.0	30.0
2915012037229PT	L 196	NO	AFTER TEST	188734.	0.00200	0.00200	BASE	14.0	30.0
2925003276212PT	L 197	NO	AFTER TEST	1110.	0.00020	0.00020	BASE	14.0	30.0
2925003276214PT	L 198	NO	AFTER TEST	1832.	0.00020	0.00020	BASE	14.0	30.0
2925003276216PT	L 199	NO	AFTER TEST	3769.	0.00040	0.00040	BASE	14.0	30.0
2925010228332PT	L 200	NO	AFTER TEST	3143.	0.00080	0.00080	BASE	11.0	30.0
2925010685284PT	L 201	NO	AFTER TEST	875.	0.00010	0.00010	BASE	24.0	30.0
2925010753343PT	L 202	NO	AFTER TEST	1963.	0.00120	0.00120	BASE	12.0	30.0
2925011802149PT	L 203	NO	AFTER TEST	8909.	0.00090	0.00090	BASE	14.0	30.0
2935010078381PT	L 204	NO	AFTER TEST	891.	0.00060	0.00060	BASE	14.0	30.0
2945011441402PT	L 205	NO	AFTER TEST	1739.	0.00010	0.00010	BASE	14.0	30.0
2995005343027PT	L 206	NO	AFTER TEST	1221.	0.00030	0.00030	BASE	25.0	30.0
2995010995028PT	L 207	NO	AFTER TEST	7727.	0.00030	0.00030	BASE	16.0	30.0
2995011498836PT	L 208	NO	AFTER TEST	1475.	0.00110	0.00110	BASE	14.0	30.0
2995011595332	L 209	NO	AFTER TEST	464.	0.00090	0.00090	BASE	14.0	30.0
2995011596742	L 210	NO	AFTER TEST	1333.	0.00320	0.00320	BASE	14.0	30.0
3110011298083PT	L 211	NO	AFTER TEST	168.	0.00190	0.00190	BASE	14.0	30.0
4320011878144PT	L 212	NO	AFTER TEST	10076.	0.00010	0.00010	BASE	14.0	30.0
4710011756154PT	L 213	NO	AFTER TEST	547.	0.00040	0.00040	BASE	14.0	30.0
4710011795109PT	L 214	NO	AFTER TEST	422.	0.00020	0.00020	BASE	12.0	30.0
4810010070536	L 215	NO	AFTER TEST	3119.	0.00150	0.00150	BASE	14.0	30.0
4810010352340PT	L 216	NO	AFTER TEST	3167.	0.00010	0.00010	BASE	14.0	30.0
4810010898900	L 217	NO	AFTER TEST	1671.	0.00020	0.00020	BASE	14.0	30.0
4810010911930	L 218	NO	AFTER TEST	1714.	0.00040	0.00040	BASE	14.0	30.0
4810010944567	L 219	NO	AFTER TEST	2107.	0.00010	0.00010	BASE	14.0	30.0
4810010944568	L 220	NO	AFTER TEST	2371.	0.00020	0.00020	BASE	14.0	30.0
4820003050209 1P	L 221	NO	AFTER TEST	2844.	0.00260	0.00260	BASE	13.0	30.0
4820003133307	L 222	NO	AFTER TEST	3557.	0.00020	0.00020	BASE	14.0	30.0

Table E-1. Detailed LRU Information for F-15C PACAF (Continued)

4820003373985	L 223	NO	AFTER TEST	505.	0.00000	0.00000	BASE	20.0	30.0
4820010681105	L 224	NO	AFTER TEST	9574.	0.00030	0.00030	BASE	24.0	30.0
4820010955359PT	L 225	NO	AFTER TEST	7054.	C.00090	0.00090	BASE	14.0	30.0
4820011526285PT	L 226	NO	AFTER TEST	920.	0.00020	0.00020	BASE	14.0	30.0
5821010934574	L 227	NO	AFTER TEST	7482.	0.00090	0.00090	BASE	14.0	30.0
5821010934632	L 228	NO	AFTER TEST	2602.	0.00090	0.00090	BASE	14.0	30.0
5821010934635	L 229	NO	AFTER TEST	14304.	0.00410	0.00410	BASE	14.0	30.0
5821010934663	L 230	NO	AFTER TEST	1055.	0.00090	0.00090	BASE	16.0	30.0
5821010934664	L 231	NO	AFTER TEST	1248.	0.00060	0.00060	BASE	14.0	30.0
5821010939985	L 232	NO	AFTER TEST	881.	0.00030	0.00030	BASE	14.0	30.0
5821011178463	L 233	NO	AFTER TEST	2152.	0.00240	0.00240	BASE	29.0	30.0
5821011280394	L 234	NO	AFTER TEST	10500.	0.00300	0.00300	BASE	14.0	30.0
5821011498710	L 235	NO	AFTER TEST	748.	0.00030	0.00030	BASE	16.0	30.0
5821011498809	L 236	NO	AFTER TEST	1959.	0.00190	0.00190	BASE	16.0	30.0
5826010603893	L 237	NO	AFTER TEST	6265.	0.00080	0.00080	BASE	14.0	30.0
5841010451066	L 238	NO	AFTER TEST	3817.	0.00030	0.00030	BASE	33.0	30.0
5841010510385	L 239	NO	AFTER TEST	6445.	0.00020	0.00020	BASE	14.0	30.0
5841010588861	L 240	NO	AFTER TEST	3529.	0.00010	0.00010	BASE	13.0	30.0
5841010630856	L 241	NO	AFTER TEST	108154.	0.00080	0.00080	BASE	11.0	30.0
5841010714135	L 242	NO	AFTER TEST	4600.	0.00020	0.00020	BASE	14.0	30.0
5841010808787	L 243	NO	AFTER TEST	20920.	0.00060	0.00060	BASE	16.0	30.0
5841011712635	L 244	NO	AFTER TEST	3728.	0.00070	0.00070	BASE	14.0	30.0
5841011713031	L 245	NO	AFTER TEST	3213.	0.00130	0.00130	BASE	14.0	30.0
5865000037461EW	L 246	NO	AFTER TEST	817.	0.00100	0.00100	BASE	12.0	30.0
5865000037464EW	L 247	NO	AFTER TEST	5800.	0.00390	0.00390	BASE	10.0	30.0
5865000076945EW	L 248	NO	AFTER TEST	3208.	0.00980	0.00980	BASE	23.0	30.0
5865000076949EW	L 249	NO	AFTER TEST	4627.	0.01170	0.01170	BASE	16.0	30.0
5865000076950EW	L 250	NO	AFTER TEST	1530.	0.00290	0.00290	BASE	20.0	30.0
5865000094381EW	L 251	NO	AFTER TEST	9730.	0.00290	0.00290	BASE	12.0	30.0
5865000233361EW	L 252	NO	AFTER TEST	822.	0.00290	0.00290	BASE	11.0	30.0
5865001559243EW	L 253	NO	AFTER TEST	559.	0.00130	0.00130	BASE	9.0	30.0
5865001559266EW	L 254	NO	AFTER TEST	8980.	0.00780	0.00780	BASE	9.0	30.0
5865001559489EW	L 255	NO	AFTER TEST	1830.	0.00630	0.00630	BASE	16.0	30.0
5865001559499EW	L 256	NO	AFTER TEST	890.	0.00290	0.00290	BASE	12.0	30.0
5865001627964EW	L 257	NO	AFTER TEST	421[illegible].	0.00690	0.00690	BASE	13.0	30.0
5865001854444EW	L 258	NO	AFTER TEST	4177.	0.01270	0.01270	BASE	19.0	30.0
5865001955987EW	L 259	NO	AFTER TEST	1368.	0.00390	0.00390	BASE	16.0	30.0
5865001994210EW	L 260	NO	AFTER TEST	12929.	0.01370	0.01370	BASE	16.0	30.0
5865003073292EW	L 261	NO	AFTER TEST	433.	0.02050	0.02050	BASE	17.0	30.0
5865003151482EW	L 262	NO	AFTER TEST	2680.	0.00200	0.00200	BASE	11.0	30.0
5865003151491EW	L 263	NO	AFTER TEST	825.	0.02050	0.02050	BASE	13.0	30.0
5865003151499EW	L 264	NO	AFTER TEST	1973.	0.00780	0.00780	BASE	16.0	30.0
5865003217636EW	L 265	NO	AFTER TEST	1569.	0.00490	0.00490	BASE	11.0	30.0
5865003217650EW	L 266	NO	AFTER TEST	362.	0.00030	0.00030	BASE	11.0	30.0
5865003655459EW	L 267	NO	AFTER TEST	1843.	0.01760	0.01760	BASE	12.0	30.0
5865003713344EW	L 268	NO	AFTER TEST	7904.	0.01760	0.01760	BASE	18.0	30.0
5865004438630EW	L 269	NO	AFTER TEST	610.	0.00030	0.00030	BASE	22.0	30.0
5865004520326EW	L 270	NO	AFTER TEST	271.	0.00350	0.00350	BASE	14.0	30.0
5865004520327EW	L 271	NO	AFTER TEST	185.	0.00200	0.00200	BASE	12.0	30.0
5865004520328EW	L 272	NO	AFTER TEST	611.	0.00140	0.00140	BASE	11.0	30.0
5865004671140EW	L 273	NO	AFTER TEST	3631.	0.00790	0.00790	BASE	14.0	30.0
5865004671191EW	L 274	NO	AFTER TEST	4177.	0.00330	0.00330	BASE	14.0	30.0
5865004723317EW	L 275	NO	AFTER TEST	822.	0.00100	0.00100	BASE	14.0	30.0
5865004764442EW	L 276	NO	AFTER TEST	6273.	0.01470	0.01470	BASE	16.0	30.0
5865004764443EW	L 277	NO	AFTER TEST	3703.	0.02440	0.02440	BASE	16.0	30.0
5865004775921EW	L 278	NO	AFTER TEST	2818.	0.00100	0.00100	BASE	12.0	30.0
5865004775923EW	L 279	NO	AFTER TEST	2366.	0.00000	0.00000	BASE	14.0	30.0

Table E-1. Detailed LRU Information for F-15C PACAF (Continued)

5865005562035EW	L 280	NO	AFTER TEST	331.	0.00200	0.00200	BASE	18.0	30.0
5865005562036EW	L 281	NO	AFTER TEST	531.	0.00390	0.00390	BASE	14.0	30.0
5865005562037EW	L 282	NO	AFTER TEST	161.	0.00180	0.00180	BASE	11.0	30.0
5865005562038EW	L 283	NO	AFTER TEST	1270.	0.00200	0.00200	BASE	15.0	30.0
5865005562039EW	L 284	NO	AFTER TEST	1245.	0.01170	0.01170	BASE	16.0	30.0
5865005562041EW	L 285	NO	AFTER TEST	224.	0.00100	0.00100	BASE	22.0	30.0
5865005562055EW	L 286	NO	AFTER TEST	376.	0.00390	0.00390	BASE	15.0	30.0
5865005562062EW	L 287	NO	AFTER TEST	1352.	0.00100	0.00100	BASE	17.0	30.0
5865005562103EW	L 288	NO	AFTER TEST	951.	0.00290	0.00290	BASE	8.0	30.0
5865005562104EW	L 289	NO	AFTER TEST	751.	0.00720	0.00720	BASE	16.0	30.0
5865005562114EW	L 290	NO	AFTER TEST	1293.	0.00610	0.00610	BASE	15.0	30.0
5865005562122EW	L 291	NO	AFTER TEST	203.	0.00420	0.00420	BASE	17.0	30.0
5865006035397EW	L 292	NO	AFTER TEST	560.	0.00070	0.00070	BASE	25.0	30.0
5865006035404EW	L 293	NO	AFTER TEST	980.	0.00170	0.00170	BASE	16.0	30.0
5865006035409EW	L 294	NO	AFTER TEST	3999.	0.00120	0.00120	BASE	16.0	30.0
5865006035457EW	L 295	NO	AFTER TEST	71.	0.00070	0.00070	BASE	13.0	30.0
5865006035458EW	L 296	NO	AFTER TEST	692.	0.00030	0.00030	BASE	18.0	30.0
5865006035460EW	L 297	NO	AFTER TEST	722.	0.00020	0.00020	BASE	32.0	30.0
5865006035461EW	L 298	NO	AFTER TEST	664.	0.00070	0.00070	BASE	19.0	30.0
5865006035462EW	L 299	NO	AFTER TEST	5031.	0.00120	0.00120	BASE	14.0	30.0
5865006035520EW	L 300	NO	AFTER TEST	714.	0.00040	0.00040	BASE	26.0	30.0
5865006035524EW	L 301	NO	AFTER TEST	3592.	0.00130	0.00130	BASE	14.0	30.0
5865007598099EW	L 302	NO	AFTER TEST	'0973.	0.00240	0.00240	BASE	10.0	30.0
5865010134840EW	L 303	NO	AFTER TEST	1338.	0.00290	0.00290	BASE	16.0	30.0
5865010135205EW	L 304	NO	AFTER TEST	292.	0.00200	0.00200	BASE	10.0	30.0
5865010135206EW	L 305	NO	AFTER TEST	560.	0.00200	0.00200	BASE	15.0	30.0
5865010142724EW	L 306	NO	AFTER TEST	2554.	0.00010	0.00010	BASE	15.0	30.0
5865010346003EW	L 307	NO	AFTER TEST	1423.	0.00050	0.00050	BASE	15.0	30.0
5865010599021EW	L 308	NO	AFTER TEST	1315.	0.00030	0.00030	BASE	24.0	30.0
5865010650216EW	L 309	NO	AFTER TEST	1789.	0.00050	0.00050	BASE	8.0	30.0
5865010666206EW	L 310	NO	AFTER TEST	1396.	0.00080	0.00080	BASE	21.0	30.0
5865010668149EW	L 311	NO	AFTER TEST	1326.	0.00070	0.00070	BASE	30.0	30.0
5865010770497EW	L 312	NO	AFTER TEST	6013.	0.01560	0.01560	BASE	16.0	30.0
5865010844520EW	L 313	NO	AFTER TEST	2138.	0.00100	0.00100	BASE	22.0	30.0
5865010861000EW	L 314	NO	AFTER TEST	2138.	0.00300	0.00300	BASE	11.0	30.0
5865010861001EW	L 315	NO	AFTER TEST	3097.	0.00420	0.00420	BASE	14.0	30.0
5865010861002EW	L 316	NO	AFTER TEST	2138.	0.00070	0.00070	BASE	22.0	30.0
5865010879065EW	L 317	NO	AFTER TEST	675.	0.00020	0.00020	BASE	14.0	30.0
5865010880956EW	L 318	NO	AFTER TEST	2141.	0.00030	0.00030	BASE	13.0	30.0
5865010881019EW	L 319	NO	AFTER TEST	2647.	0.00170	0.00170	BASE	17.0	30.0
5865010881025EW	L 320	NO	AFTER TEST	12248.	0.00130	0.00130	BASE	14.0	30.0
5865010889067EW	L 321	NO	AFTER TEST	716.	0.00010	0.00010	BASE	15.0	30.0
5865010972494EW	L 322	NO	AFTER TEST	602.	0.00010	0.00010	BASE	14.0	30.0
5865010998141EW	L 323	NO	AFTER TEST	650.	0.00060	0.00060	BASE	14.0	30.0
5865010999833EW	L 324	NO	AFTER TEST	689.	0.00030	0.00030	BASE	33.0	30.0
5865011172948EW	L 325	NO	AFTER TEST	497.	0.00010	0.00010	BASE	14.0	30.0
5865011185359EW	L 326	NO	AFTER TEST	3042.	0.00030	0.00030	BASE	23.0	30.0
5865011339957EW	L 327	NO	AFTER TEST	1938.	0.00190	0.00190	BASE	14.0	30.0
5865011341091EW	L 328	NO	AFTER TEST	3152.	0.00100	0.00100	BASE	14.0	30.0
5865011549042EW	L 329	NO	AFTER TEST	2580.	0.00040	0.00040	BASE	16.0	30.0
5865011701119EW	L 330	NO	AFTER TEST	1588.	0.00010	0.00010	BASE	14.0	30.0
5865012112336EW	L 331	NO	AFTER TEST	3200.	0.00090	0.00090	BASE	14.0	30.0
5865012119086EW	L 332	NO	AFTER TEST	2000.	0.00170	0.0[illegible]70	BASE	14.0	30.0
5895001151029	L 333	NO	AFTER TEST	1309.	0.00260	0.00260	BASE	16.0	30.0
5895010444987	L 334	NO	AFTER TEST	1303.	0.00070	0.00070	BASE	14.0	30.0
5895010959593	L 335	NO	AFTER TEST	4093.	0.00320	0.00320	BASE	14.0	30.0
5895011132491	L 336	NO	AFTER TEST	2630.	0.00010	0.00010	BASE	14.0	30.0

Table E-1. Detailed LRU Information for F-15C PACAF (Continued)

5895011184625	L 337	NO	AFTER TEST	263.	0.00090	0.00090	BASE	10.0	30.0
5945003696992	L 338	NO	AFTER TEST	1725.	0.00020	0.00020	BASE	20.0	30.0
5985010304158EW	L 339	NO	AFTER TEST	2876.	0.00050	0.00050	BASE	14.0	30.0
5985010304159EW	L 340	NO	AFTER TEST	2549.	0.00400	0.00400	BASE	14.0	30.0
5995003904515CW	L 341	NO	AFTER TEST	6397.	0.00090	0.00090	BASE	15.0	30.0
5995011310957EW	L 342	NO	AFTER TEST	4874.	0.00100	0.00100	BASE	14.0	30.0
6115004690710	L 343	NO	AFTER TEST	10374.	0.00190	0.00190	BASE	14.0	30.0
6115011213632UH	L 344	NO	AFTER TEST	19692.	0.00120	0.00120	BASE	14.0	30.0
6340003327300	L 345	NO	AFTER TEST	2972.	0.00020	0.00020	BASE	14.0	30.0
6340010772900NT	L 346	NO	AFTER TEST	3791.	0.00040	0.00040	BASE	11.0	30.0
6605003142536	L 347	NO	AFTER TEST	2013.	0.00140	0.00140	BASE	14.0	30.0
6605010423335	L 348	NO	AFTER TEST	8902.	0.00160	0.00160	BASE	14.0	30.0
6605010445026	L 349	NO	AFTER TEST	3405.	0.00050	0.00050	BASE	15.0	30.0
6605010470163	L 350	NO	AFTER TEST	1386.	0.00020	0.00020	BASE	15.0	30.0
6605010977155	L 351	NO	AFTER TEST	1276.	0.00070	0.00070	BASE	14.0	30.0
6610000000122	L 352	NO	AFTER TEST	14082.	0.00150	0.00150	BASE	12.0	30.0
6610001342251	L 353	NO	AFTER TEST	3708.	0.00030	0.00030	BASE	10.0	30.0
6610001342259	L 354	NO	AFTER TEST	1643.	0.00140	0.00140	BASE	13.0	30.0
6610001342260	L 355	NO	AFTER TEST	4307.	0.00140	0.00140	BASE	11.0	30.0
6610001600905	L 356	NO	AFTER TEST	3745.	0.00170	0.00170	BASE	17.0	30.0
6610002963574	L 357	NO	AFTER TEST	939.	0.00050	0.00050	BASE	10.0	30.0
6610003036706	L 358	NO	AFTER TEST	2411.	0.00040	0.00040	BASE	12.0	30.0
6610003293495	L 359	NO	AFTER TEST	1214.	0.00150	0.00150	BASE	12.0	30.0
6610003616686	L 360	NO	AFTER TEST	564.	0.00070	0.00070	BASE	10.0	30.0
6610005357722	L 361	NO	AFTER TEST	2199.	0.00380	0.00380	BASE	15.0	30.0
6610010379144	L 362	NO	AFTER TEST	19047.	0.00480	0.00480	BASE	14.0	30.0
6610010424831	L 363	NO	AFTER TEST	17922.	0.00600	0.00600	BASE	14.0	30.0
6610010933356	L 364	NO	AFTER TEST	3624.	0.00070	0.00070	BASE	16.0	30.0
6610011676617	L 365	NO	AFTER TEST	11588.	0.00570	0.00570	BASE	20.0	30.0
6610011687039	L 366	NO	AFTER TEST	928.	0.00030	0.00030	BASE	14.0	30.0
6610011687042	L 367	NO	AFTER TEST	927.	0.00010	0.00010	BASE	14.0	30.0
6610011692283	L 368	NO	AFTER TEST	670.	0.00010	0.00010	BASE	14.0	30.0
6615001377514	L 369	NO	AFTER TEST	29601.	0.00170	0.00170	BASE	13.0	30.0
6615002624314	L 370	NO	AFTER TEST	13993.	0.00030	0.00030	BASE	13.0	30.0
6615003036728	L 371	NO	AFTER TEST	30605.	0.00830	0.00830	BASE	12.0	30.0
6615003036730	L 372	NO	AFTER TEST	1867.	0.00120	0.00120	BASE	16.0	30.0
6615010154794	L 373	NO	AFTER TEST	27553.	0.00280	0.00280	BASE	20.0	30.0
6615010214234	L 374	NO	AFTER TEST	5452.	0.00060	0.00060	BASE	14.0	30.0
6615010950962	L 375	NO	AFTER TEST	26189.	0.00300	0.00300	BASE	14.0	30.0
6615011497475	L 376	NO	AFTER TEST	13596.	0.00110	0.00110	BASE	14.0	30.0
6620001487306	L 377	NO	AFTER TEST	2259.	0.00110	0.00110	BASE	14.0	30.0
6620004689824	L 378	NO	AFTER TEST	3871.	0.00110	0.00110	BASE	9.0	30.0
6620010872354	L 379	NO	AFTER TEST	3361.	0.00220	0.00220	BASE	12.0	30.0
6645000763050	L 380	NO	AFTER TEST	546.	0.00180	0.00180	BASE	12.0	30.0
6680010684284	L 381	NO	AFTER TEST	662.	0.00200	0.00200	BASE	10.0	30.0
6680011033419	L 382	NO	AFTER TEST	6351.	0.00180	0.00180	BASE	19.0	30.0
6680011066215	L 383	NO	AFTER TEST	6984.	0.00150	0.00150	BASE	17.0	30.0
6680011288000PT	L 384	NO	AFTER TEST	10712.	0.00730	0.00730	BASE	14.0	30.0
6685003336763	L 385	NO	AFTER TEST	415.	0.00050	0.00050	BASE	16.0	30.0
6685010482889NT	L 386	NO	AFTER TEST	2984.	0.00140	0.00140	BASE	14.0	30.0
7021004775716	L 387	NO	AFTER TEST	49372.	0.00070	0.00070	BASE	14.0	30.0

GLOSSARY

ACIM	Availability Centered Inventory Model
AFLC	Air Force Logistics Command
AIS	Avionics Intermediate Shop
ATF	Advanced Tactical Fighter
BLSS	Base Level Self-Sufficiency Spares
CAC	Combat Analysis Capability
CASEE	Comprehensive Aircraft Support Effectiveness Evaluation (model)
CIRF	Centralized Intermediate Repair Facility
DMAS	Dyna-METRIC Microcomputer Analysis System (model)
DRC	Dynamics Research Corporation
Dyna-METRIC	Dynamic Multi-Echelon Technique for Recoverable Item Control (model)
FMC	Fully Mission Capable
IOC	Initial Operational Capability
JIAWG	The Joint Integrated Avionics Working Group
LCOM	Logistic Composite Model
LHX	Light Helicopter Experimental
LRM	Line Replaceable Module
LRUs	Line Replaceable Units
MIME	Multi-Item, Multi-Echelon
MTBF	Mean Time Between Failures
MTCBF	Mean Time Between Critical Failure
MTTR	Mean Time To Repair
NFMC	Not Fully Mission Capable
NMCS	Not Mission Capable Status
NOP	Non-optimized
NRTS	Not Repairable This Station
OLMT	O-Level Maintenance Types
OSD	Office of the Secretary of Defense
PACAF	Pacific Air Force
QPA	Quantity Per Aircraft
R&M	Reliability and Maintainability

RR	Remove and Repair
RRR	Remove, Repair and Replace
SBSS	Standard Base Supply System
SESAME	Selective Stockage for Availability, Multi-Echelon (model)
SPECTRUM	Simulation Package for the Evaluation by Computer Technique of Readiness, Utilization, and Maintenance (model)
SRUs	Shop Replaceable Units
TAC	Tactical Air Command
TAT	Turn Around Time
TMS	Type-Model-Series
VHSIC	Very High Speed Intergrated Circuits
WRSK	War Reserve Spares Kits
WSMIS	Weapon System Management Information System

Distribution List
for P-2251
WEAPON RELIABILITY AND LOGISTIC SUPPORT COSTS IN A COMBAT ENVIRONMENT

Total Copies: 100

DEPARTMENT OF DEFENSE	Copies
Mr. Thomas Parry Chief, Weapons Systems Improvement and Analysis Division Defense Systems Program Office 5109 Leesburg Pike, Room 306 Falls Church, VA 22041-3246	15
Mr. Martin Meth Director, Weapon Support Improvement Group Room 2B322, The Pentagon Washington, D.C. 20301	1
Mr. Robert C. Duncan Director, Defense Research and Engineering Room 3E1006, The Pentagon Washington, D.C. 20301	1
Mr. Robert McCormack Assistant Secretary, Production and Logistics Room 3E808, The Pentagon Washington, D. C. 20301	1
Dr. David S. C. Chu Assistant Secretary for Program Analysis and Evaluation Room 3E836, The Pentagon Washington, D.C. 20301	1
Dr. John Morgan Director, Force Structure and Support Analysis Division OASD (PA&E) Room 2D27, The Pentagon Washington, D.C. 20301	1
Mr. Robert Croteau Director, Tactical Air Division PA&E Room 2C281, The Pentagon Washington, D.C. 20301	1
Defense Technical Information Center Cameron Station Alexandria, VA 22314	2

DEPARTMENT OF THE ARMY

Mr. David J. Trosky
Chief, Product Assurance/Test Division
Light Helicopter Program
AMCPEO-LHX
4200 Goodfellow Blvd.
St. Louis, Mo 63120-1798 1

DEPARTMENT OF THE NAVY

Mr. Michael G. Henry
Assistant Director for Readiness Appraisal (OP-81D)
Program Resources Appraisal Division
Office of the Deputy CNO (Navy Program Planning)
Room 4A478, The Pentagon
Washington, D.C. 20350 1

DEPARTMENT OF THE AIR FORCE

Dr. Jerry Klion
Rome Air Development Center
RADC/RBE
Griffis Air Force Base, NY 13441-5700 1

HQ AFSC/EN
Andrews Air Force Base
Washington, DC 20334-5000 1

Lt. Gen. Charles C. McDonald
HQ AF/LE
The Pentagon, Room 4E260
Washington, DC 20330 1

Col. Larry D. Griffin
AFLC/MME
Wright-Patterson Air Force Base, Ohio 45433 15

Ms. Barbara Weiland
AFLC/XPSA
Wright-Patterson Air Force Base, Ohio 45433 1

Lt. Gen. John M. Loh
Commander, Aeronautical Systems Division
Wright-Patterson Air Force Base, Ohio 45433 1

Mr. John Vice
WRDC/FIVS/SURVIAC
Wright-Patterson Air Force Base, Ohio 45433-6553 1

Mr. James McManus
AFHRL
Wright-Patterson Air Force Base, Ohio 45433 1

Ms. Mary Potter
AFLC/LOC/TLPW
Wright-Patterson Air Force Base, Ohio 45433 1

Mr. Panzarella
HQ AFLC/CCN
Office of the Chief Scientist
Wright-Patterson Air Force Base, Ohio 45433 1

HQ AFLC/CV
Office of the Vice Commander
Wright-Patterson Air Force Base, Ohio 45433 1

HQ AFLC/MM
Wright-Patterson Air Force Base, Ohio 45433 1

AFALC/CC
Wright-Patterson Air Force Base, Ohio 45433 1

Dr. Jerry Crane
HQ AFLC/MMR
Wright-Patterson Air Force Base, Ohio 45433 5

Mr. John Halpin
ASD/EN (PA)
Wright-Patterson Air Force Base, Ohio 45433 1

Ms. Sidney Gerard
AFLC/MMIRS
Wright-Patterson Air Force Base, Ohio 45433 1

Dr. Richard Luckew
WRDC/AAA
Wright-Patterson Air Force Base, Ohio 45433-6543 1

COL Michael Borky
ASD/YFA
Joint Integrated Avionics Working Group
Wright-Patterson Air Force Base, Ohio 45433 1

INDUSTRIAL ORGANIZATIONS

Mr. Keith Collier
Director, Systems Analysis and Integration
McDonnell Aircraft Company
P.O. Box 516
Saint Louis, MO 63166-0516 1

Mr. Irvin Krause
Center for Manufacturing Technology
144 Middlesex Turnpike
Burlington, MA 01803 1

Dr. Jerry Klion
Rome Air Development Center
RADC/RBE
Griffis Air Force Base, NY 13441-5700 1

Dr. Peter Evanovich
Center for Naval Analyses
4401 Ford Avenue
P.O. Box 16268
Alexandria, VA 22302-0268 1

Dr. J. R. Gebman
The RAND Corporation
1700 Main Street
Santa Monica, CA 90406-2138 1

Institute for Defense Analyses 34

Gen. William Y. Smith	1
Dr. Robert Roberts	1
Mr. Philip L. Major	1
Dr. Jeffrey Grotte	1
Mr. Paul Goree	1
Dr. Peter Brooks	1
Mr. Stanley A. Horowitz	5
Dr. William J. Schultis	1
Dr. Karen W. Tyson	10
Ms. Mei Ling Eng	1
Ms. Barbara Junghans	1
Mr. Mitchell Robinson	1
Mr. D. Graham McBryde	1
Mr. Stephen Welman	1
Dr. Matthew Goldberg	1
Dr. J. R. Nelson	1
C&D	5